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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLVII.

SESSION 1876–77.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. xlvi., p. 289, line 14 from bottom, for *shore* read *stone.*
„ pp. vi, 365 and 388, for *Rélo*houbek read *Bě*lohoubek.

Vol. xvii., plate 5, fig. 11, for $w = 1{\cdot}18$ ton read $w = 0{\cdot}36$ ton.
„ „ „ 11, „ $w' = 1{\cdot}38$ ton „ $w' = 0{\cdot}42$ ton.
„ „ „ 12, „ $w = 0{\cdot}88$ ton „ $w = 0{\cdot}27$ ton.
„ „ „ 12, „ $w' = 2{\cdot}46$ tons „ $w' = 0{\cdot}75$ ton.
These weights are given correctly in the text.

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1876-77.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

November 14, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,451.—"The Japan Lights." By RICHARD HENRY BRUNTON, M. Inst. C.E.

THE Government of Japan, in entering into friendly relations with foreign powers, stipulated that certain ports were to be open, and that mercantile operations were to be confined to those places. These ports are:

1. Hakodate, in the island of Yezo.
2. Yokohama, 20 miles from the northern capital of the country, Yedo, or Tôkiô.
3. Kôbe, 50 miles from the southern capital, Kiôto, and near the entrance to the Inland Sea.
4. Ôzaka, between Kôbe and Kiôto, being 20 miles from the former.
5. Nagasaki, in the south-west portion of the island of Kiusiu.
6. Niigata, on the west coast of the Main Island.

The principal trade is at Yokohama, where from two hundred to three hundred foreign-owned vessels of large size annually resort. The next places in importance are Kôbe and Nagasaki, at each of which about one hundred and seventy vessels arrive every year. Hakodate is in a high latitude, and its trade is almost entirely confined to the summer months, but it is at no time of any great extent. Niigata and Ôzaka are visited by few ships. All these ports, however, are the rendezvous for a considerable native trade, which is every year increasing.

The foreign powers arranged, and it forms one of the clauses in the existing treaties, that the Japanese Government should "provide the treaty ports with such lights as may be necessary to render secure the navigation of the approaches to the said ports." On the 17th of November, 1866, Sir Harry S. Parkes, K.C.B., H.B.M. representative, directed the attention of the Japanese Government to the existence of this stipulation, and requested that steps might be taken to carry out its purport.

The French and American ministers shortly afterwards made similar representations, and a favourable reply was received from the Japanese ministers early in December of the same year. Sir H. S. Parkes had previously received suggestions from naval officers and others relative to the most important sites for the lights, and these he laid before the Japanese Government. The erection of eleven lights was agreed to, and Sir H. S. Parkes was requested to use his influence with Her Majesty's Government, in order that the necessary apparatus and the assistance required to establish lighthouses might be obtained. The matter having been referred to the Board of Trade, that department consulted the Trinity House, and eventually, on the 6th of November, 1867, Messrs. D. and T. Stevenson, MM. Inst. C.E., the Engineers to the Commissioners of Northern Lights, were desired to select suitable persons to undertake the design and construction of the lighthouses, and to introduce the lighthouse service into Japan. The Board of Trade had the general management and supervision of the arrangements, while the Messrs. Stevenson, who pointed out the difficulties likely to be experienced from the constant recurrence of earthquake shocks in Japan, had charge of the construction of the apparatus for six of the lights which had been ordered.

The Author received the appointment of Chief Engineer in February 1868, and he arrived in Japan in August of the same year.

Out of more than twenty-five sites suggested by those to whom the matter had been referred in Japan, five points appeared to be generally concurred in. (Plate 1.) These were:—A second order revolving light at Ôshima (Kashinosaki); a first order fixed light at Shiwomisaki; a first order fixed light at Iwoshima; a first order fixed light at Satanomisaki; and a lightship at Hakodate.

It was found, however, impossible to select from the various suggestions the most advantageous positions for the remaining six lights authorized by the Japanese Government. A proposal was therefore made by Sir H. S. Parkes to complete the necessary information by a mixed Commission of the senior naval officers of England, France, and America then in Japan, the Japanese

Government being also represented on it. This Commission consisted of Captain Hewett, of the English navy; Commodore Goldsborough, of the United States navy; and Commandant Amet, of the French navy. The Japanese war-steamer "Fujiyama" was placed at the disposal of these officers, and they visited the various points in November 1867. They agreed in recommending a first order fixed light on Noshima; a first order fixed light on Mikomoto (Rock Island); a second order flashing light on Tsurugisaki (Sagami); a third order fixed light on Kannonsaki; a red floating light at Yokohama harbour; as well as several buoys and beacons in the Gulf of Yedo.

Some time previous to the formation of this Commission the apparatus for several lights had been ordered from France through a staff of French engineers, who were then engaged in forming an arsenal at Yokoska, on the west coast of the Gulf of Yedo, about 10 miles from Yokohama. These were intended to light the approaches to the arsenal; but the Commission recommended that they should be placed on those points most urgently requiring illumination. It was afterwards found that the only spots suitable for them in the Gulf of Yedo were Noshima and Kannonsaki. The first order fixed apparatus from France was accordingly placed at Noshima, and the third order fixed apparatus at Kannonsaki, and these two lighthouses were erected under the superintendence of the French engineers above mentioned.

On arriving in Japan, the Author examined the sites of the lighthouses which had been decided on; and, as they were spread over 1,500 miles of coast, and there were no means of internal communication, Admiral Sir Henry Keppel, then on the Japan station, was induced to grant the use of H.M.S. "Manilla" for a voyage of inspection. In addition to collecting information and taking the requisite observations in regard to those points already decided on, the Author received instructions to inspect and report upon the best method of lighting the Inland Sea and the approaches to Kôbe and Ôzaka; for which purpose the Japanese Government, in the beginning of 1867, had authorized the apparatus for five additional lights. The Inland Sea, separating the main island from Kiusiu and Shikoku, is about 250 miles long, and, at some places, it is 50 miles wide; it is filled with several thousand small islands, and navigation is carried on through recognised channels between them. It may be judged, therefore, that to place a light on every point in the Inland Sea requisite to render navigation through it practicable, on dark nights, would be a work of magnitude and of doubtful utility.

On the other hand a few lights might be so placed that, with their assistance, a considerable portion of the sea would be navigable at night, and vessels would be guided to places where they might anchor with safety and wait for daylight.

The proposals made by the Author were based on the following principles. 1st. To put no light where the headlands are bold and well defined, or where no hidden dangers exist. 2nd. Where there are difficult and dangerous channels, through which vessels could not proceed in dark weather, to place lights to lead them into a safe anchorage where they can wait for daylight; and, if possible, in such a position that advantage may be taken of them for going through the channel. 3rd. Where a light would render a channel easy to pass through, which, without it, would be difficult, or where a light is likely to be required to give mariners a clue to their position, regarding which they may, at night, get easily confused among the numerous islands, a light should be placed.

Having regard to these considerations, the Author fixed upon the following points at the approaches to Kôbe, and Ôzaka, and in the Inland Sea, as being the most advantageous:—A third order fixed light at Tomagaishima; a fourth order fixed light at Temposan (Ôzaka); a fourth order fixed light (red) at Wadanomisaki (Kôbe); a first order fixed light at Yesaki (Awaji); a fourth order fixed light at Nabeshima; a third order fixed light at Tsurishima; a third order fixed light at Hesaki; and a fourth order fixed light at Rockuren. These proposals were laid before various nautical authorities. They received general approval, and the erection of the lighthouses was ultimately authorized.

Soon after the completion of the first two or three lighthouses, the Government showed its appreciation of them by deciding that the old system of wood fires should be abolished, and that properly illuminated lighthouses should take their place. A notification was issued by the Council of State calling upon the local authorities to name the places at which local lights were needed, and instructing them that the old system of wood fires must be discontinued. The result of this notification is that many applications for small lights have been received from all parts of the country. But as the Imperial Government has, except in a few important cases, refused to bear the expense of these lights, and as the local governments are generally unable to do so, not many of the proposals have as yet been carried out. Eleven such lights are now established, and from ten to fifteen others are under consideration.

Those which have been completed are:—A staff light on the pier in Yokohama harbour; a fifth order fixed light at Shinagawa, in Yedo harbour;[1] a fifth order fixed light at Jôkashima, near the entrance to the Gulf of Yedo;[1] a sixth order fixed red light at Irôsaki, near Mikomoto (Rock Island); a fourth order fixed light at Sugashima, the entrance to Toba harbour; a fourth order revolving light at the entrance to Matoya harbour; a fourth order red fixed light at Shirasu, west of Shimonoseki Straits; a staff light on Noshiaf, the easternmost point of the island of Yezo; a staff light in Nemuro harbour, in Yezo; a staff light at Awomori harbour; and a staff light at Ishi-no-maki, at the mouth of the river Kita-kami.

The Government, desirous of further perfecting the illumination of the coast, decided on erecting several ocean lights on those points most in need of illumination. These are in addition to the lights already specified, which were demanded by the treaty powers. A full and complete scheme for the illumination of the entire coast was drawn up, and those sites which were considered most important were first dealt with. Seven of these lighthouses are completed, and the positions for thirty others have been visited, examined, and reported on. Before finally deciding to erect any lighthouse, the Author submitted his proposals to the naval authorities in Japan at the time, and to many captains of vessels trading on the coast. Captain St. John, of H.M. surveying ship "Sylvia," gave especial attention to the matter, and rendered great assistance by his advice.

These seven lights are situated as follows:—A second order fixed light at Siriyasaki, the north-easternmost point of the main island; a first order revolving light at Kinkasan, east coast, north of Yokohama; a first order revolving light at Inuboyesaki, east coast, north of Yokohama; a first order revolving light at Omaesaki, south coast; a first order flashing light at Kadoshima, west coast, north of Shimonoseki; a second order fixed light at Yebosishima, west coast, south of Shimonoseki; and a fourth order fixed light at Haneda, Gulf of Yedo.

The apparatus for these lights, as well as for the harbour lights already mentioned, was ordered, without the intervention of the Board of Trade, through Messrs. D. and T. Stevenson, who, in September 1871, were appointed Consulting Engineers to the Japanese Lighthouse Department.

A complete list of the lighthouses, lightships, buoys and beacons established by the Author on the coast of Japan will be found in the Appendix.

In designing the lighthouses the most important point for consideration was the liability of the country to the periodical recurrence of earthquakes. No definite records had been kept of these disturbances, nor could data be procured as to the localities most subject to them. It is well known, however, that slight shocks are of frequent occurrence, and that, during the present century, fifteen shocks of a destructive character have been experienced. These were felt in different parts of the country, the northern capital, Yedo, being most subject to them, where five out of the fifteen occurred, the remaining ten being pretty equally distributed. The palace of the Emperor at Kiôto was destroyed by an earthquake in 1828, as well as most of the temples with which that city abounded. In 1846, in the province of Shinano, on the west coast, the earth swallowed up eighteen houses, five thousand dwellings being at the same time destroyed. The most recent destructive earthquake, in the year 1855, was chiefly felt at Yedo, when the trembling of the earth continued for one month, and eighty severe shocks occurred; about one hundred and twenty thousand lives were supposed to have been lost on this occasion.

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[1] These lights were erected by the Yokoska officials.

Messrs. D. and T. Stevenson, on whom the duty of designing the apparatus for the lights devolved, deemed it necessary to "take some steps to secure these from derangement, and the lamps from partial or total extinction on the occurrence of the many modified shocks which visit the country." The arrangements carried out have been thus described by Mr. David Stevenson:—"It is evident that any sudden lateral motion of the earth, on which a building rests, must be communicated to the foundation of the structure, and thence through all the rigid and unyielding materials of which it is composed to its very summit, where the violence of the shock will be aggravated by the greater elevation of the highest point of the building above the source of motion. On fully considering this action of earthquakes, it seemed to me that what was required to neutralise their shocks was a *break* in the continuity of the rigid parts forming the structure, so as to prevent the propagation of the shock. . . . The plan I proposed for this purpose, which may, for brevity, be termed an *aseismatic joint*, is the introduction of spherical balls of bell-metal, working in cups of the same material, placed between two platforms, the lower cups being fixed to beams forming the foundation, and the upper cups being fixed to the lower beams of the superstructure, thus admitting, within a limited range, free motion of the upper over the lower part of the building."[1] The Board of Trade sanctioned this arrangement for the lights first ordered, the apparatus for these being now placed on tables having an aseismatic joint on the principle described (Plate 2, Fig. 1).

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[1] *Vide* Transactions of the Royal Scottish Society of Arts, vol. vii., p. 560.

The Author's experience of the contrivance is not altogether favourable. He finds that, while the free motion of the upper over the lower part of a structure may neutralise the effects of an earthquake shock, such free motion will, at other times, occasion inconvenient results. Thus, were such a joint placed above the foundations of a lighthouse tower, the pressure exerted by a gale of wind on the superstructure would give rise to a motion probably equally as distressing as a severe earthquake. In the same way a person stepping on one of the aseismatic tables, for the purpose of trimming or cleaning the lamps, causes the upper part to roll to such an extent that the lamps become deranged, and in the case of revolving lights the regular motion of the clock-work machinery is destroyed.

Messrs. Stevenson introduced a stout spring in a vertical position, the lower part of which was securely fixed, while the upper part was attached to a ball working in a socket in the centre of the upper table. This was intended to regulate the movement, but it was only partially successful. The problem is to form a joint sufficiently sensitive to move freely on the occasion of an earthquake, but so stiff that no inconvenient motion will be occasioned by ordinary disturbances. Messrs. Stevenson's design was, for the reasons named, not adopted in any of the other lighthouses.

From the observations of those who have examined the effects of earthquakes, and have given their attention to the subject, it may be accepted that there is a double motion in all shocks, the first movement tending to overthrow, while the second tends to restore the equilibrium. If, therefore, a building could be constructed with sufficient power of resilience, its overthrow or destruction could not occur so long as the oscillation caused by the earthquake did not go beyond its limit of equilibrium. This seems to have been the leading principle in the native architecture of the country. The houses are constructed with a light wooden framework, without diagonal struts or ties of any kind. The roofs are heavy, and the uprights which support them are mortised into horizontal beams at the top and at the bottom. The buildings are evidently designed to have a maximum of elasticity, and they can, no doubt, be, and often are, moved off the vertical to a great extent without fracture. Their efficacy in resisting severe earthquakes, however, is questionable. The system further seemed open to the objection of excessive weakness, and consequent inability to withstand the other disturbing forces to which a building is exposed. The only alternative method that seemed feasible was to give the lighthouses great weight and solidity, thereby adding to their inertia and checking their oscillation. It has been laid down by Professor Palmieri of Naples, probably the most experienced earthquake observer in the world, that although solidity and strength in a building do not afford perfect protection against an earthquake, still so long as fracture does not occur, absolute overthrow is almost impossible. This principle of solidity combined with strength was the one adopted by the Author in designing the lighthouses, and in carrying out the different details of their construction.

The various lighthouses were constructed of stone or brick, wood or iron, as found most suitable for the locality. They are generally circular at the base, and the walls have a straight batter on the outside, and are plumb on the inside. Forming a semicircle round the bases are two store-rooms, one for oil, and the other for dry stores. Paint, fuel, and additional store-rooms are erected in the grounds. The lightkeepers' dwellings are of stone or brick, and contain from six to eight rooms: the kitchens and outhouses are in separate buildings. The grounds are surrounded by a stout fence or wall, about 8 feet high.

The stone lighthouses have all been constructed of ashlar masonry. Most of the stone employed was granite, of excellent quality. In some cases a volcanic claystone, of a greyish appearance, and of a tough hard character, has been used; but there are evidences of slight deterioration in this stone on the exposed surfaces. The courses have, in all cases, been 12 inches thick; and headers, from 4 feet to 2 feet wide, have been put through the walls at every third or fifth course. The stretchers are also of large size, there being, in most cases, not more than two in the thickness of the walls.

The brick lighthouses are amongst the latest erected. The making of bricks in Japan has only been recently introduced, and their manufacture has not yet obtained such perfection as to warrant their adoption where any other material is procurable. All the bricks were specially made by men employed by the Department for the purpose. The bricks were generally well formed, and of good reliable clay; but the native workmen were negligent in carrying out the process of burning, and the bricks suffered in consequence. Every precaution was taken to reject faulty ones. Those which were used resisted a pressure of 700 lbs. on the square inch. Their porosity, however, was considerably greater than was desirable, as they absorbed about 10 to 12 per cent. of their weight of water. In order to render their liability to deterioration as slight as possible, the outsides of all brick towers have been coated with Portland-cement plaster. "Flemish" bond was adopted, and hoop-iron bond was inserted between every fifth course. The lintels, soles, and rabbets of the doors and windows are all of stone. For about 13 inches from the face of the walls the courses were jointed with Portland-cement mortar, the remainder being laid in lime mortar.

Special precautions were taken regarding the lime supplied for the works. The Japanese were formerly ignorant of the use or properties of lime mortar; and although limestone was burned by them for purposes of their own, their custom was to keep it, after it had been slaked, in straw bags for indefinite periods, and to sell it in this state. They had never adopted the system of mixing it with sand and using it as a bed for stones, the principal use to which it was put being as plaster, when it was mixed with boiled seaweed. At most of the lighthouse works lime-kilns were erected, and the limestone burned on the spot. The lime was generally pure, and good mortar was formed by mixing 1 part of it with from 3 to 5 parts of sand.

The wood adopted for the main beams, uprights, &c., of those lighthouses which were built of timber is a native production named "keaki" (*Planera Japonica*). It is hard, only a little lighter than water, with a close grain, and when of good quality of an endurable nature. But it is difficult to procure good keaki, owing to the absence of restrictions in the felling of timber. Much of the wood offered for sale is unripe or full of sap, and little is to be found which has undergone seasoning, to which process but small attention is paid by the natives. Keaki is the only hard wood grown in the country in sufficient quantity to be available for building. The favourite soft wood, for floors, linings, doors, and windows, &c., is called "shinoki" (*Chamæcyparis obtusa*). It has a beautiful white grain, and is very lasting. The other woods employed in the lighthouses are "sugi," a species of cedar (*Cryptomeria Japonica*), and "matsu," a kind of pine (*Pinus densiflora*). These are considered inferior, and decay quickly when exposed to the weather. They, however, are durable when kept dry, and have been used for the trusses of roofs and for floor-joists, &c. Most of the wooden lighthouses are octagonal at the base, the eight uprights, at the angles, resting upon square blocks of stone, founded in the earth. There is also a centre upright, from which horizontal beams radiate towards the eight outer uprights. Between these latter there are diagonal beams, crossing each other, and horizontal beams at the top of the diagonals. The beams are all secured by iron straps and bolts. The drawings for these towers were made after designs furnished by Messrs. D. and T. Stevenson. The scantlings of the timbers are greater than would have been necessary with the ordinary hard woods used in England, although it is generally believed that keaki would compare favourably with any of them in point of strength.

All iron used in Japan up to the present time has been imported from Europe, and structures formed of it are necessarily costly. Three lighthouses only have, on this account, been made of iron, and then it was adopted on account of the inaccessibility of their sites. It was found that the different parts of the lighthouse, when of iron, were more easily handled, and, after they had been fitted in their places, were more rapidly put together, than if any other material was employed. These iron towers are from 20 to 30 feet high, and are entirely cased with $\frac{1}{4}$ and $\frac{3}{16}$-inch plate, riveted to the beams. They are constructed with eight or more girder uprights, consisting of two angle-irons, 3 inches by 3 inches by $\frac{1}{2}$ inch, and a web and flange of $\frac{3}{8}$-inch plate, 12 inches wide. These support the girder beams of the different floors, as well as the lantern and apparatus. Small uprights at the angles of the towers rest upon a wrought-iron sole-plate bedded on a stone foundation. One iron screw pile lighthouse, erected at Haneda, was designed by Messrs. Stevenson, constructed in England, and sent to Japan in pieces.

There were unusual difficulties in the construction of some of the lighthouses. For instance, Mikomoto, or Rock Island Lighthouse (Plate 2, Fig. 2), has been erected on an isolated rock about 2,000 feet long by 450 feet wide, by 100 feet high, at its summit. It is situated off the harbour of Shimoda, about 80 miles south-west of Yokohama, and at a distance of 6 miles from the nearest land. All vessels on their way to Yokohama from the south pass this rock; and, as there are rocks between it and the shore, it is an extremely dangerous locality, and an important position for a light. The sides of the island are precipitous, and in heavy gales of wind green seas dash right over it. It is composed of a hard, brittle, igneous rock, worn to sharp points by the weather. The currents, which run with great velocity in the neighbourhood, cause a constant turbulence in the sea, and it is, further, subject to frequent gales. The locality is also believed to have suffered severely from earthquake shocks. From the exposed position of the rock, the construction of this lighthouse was a work of difficulty. At Shimoda a hard claystone was found, and a quarry was opened for the works. Limestone was discovered in close proximity, and a kiln was erected on the rock, where the stone was burned. It yielded an excellent lime. Communication with the rock was carried on by native-built boats, worked by the natives with extraordinary skill. The lighthouse is of stone, 58 feet high to the sole-plate of the lantern. It is in the shape of a truncated cone, and is surmounted by a capital having twenty-four Gothic arched recesses round it. The diameter at the base is 22 feet and at the top 16 feet. The thickness of the walls at the base is 6 feet and at the top 3 feet. It is fitted with a spiral staircase of keaki. The light shows all round the horizon, and a red ray of 55° is inserted, which covers all dangers between it and the shore. The work of cutting away the rock to prepare for the foundations of the tower was commenced in April 1869, and the lighthouse was first illuminated on the 1st of January, 1871.

Yebosishima (Plate 2, Figs. 7 and 8) is a conical rock 60 miles to the south-westward of Shimonoseki Straits and 10 miles off the mainland. It is passed by all vessels proceeding between the Inland Sea and Nagasaki. The island is 120 feet high, and is composed of hard basalt. Its sides are precipitous. Immense boulders, weighing upwards of 50 tons each, were found on its summit, and these had to be removed before sufficient space could be obtained for the buildings. Owing to the inaccessibility of the site an iron tower was erected. It is octagonal, 32 feet 6 inches high, and the extreme width is 23 feet 6 inches at the bottom, and 18 feet 6 inches at the top. A stone dwelling-house and a water and paint store were erected on the rock. Winding steps were cut in the face of the rock, and a tramway was laid by which the materials were conveyed to the summit. The materials were brought, as at Rock Island, in native boats, and were lifted out by shear legs, made to project over the boats, as these could only lie at some distance off. No landing could be effected unless the water was quite smooth, and progress was on this account much delayed. The works were commenced in August 1873, and the light was first exhibited on the 1st of August, 1875. A relief station has been established at the nearest point of the mainland, on one of the headlands at the entrance to Yobuko harbour. Two lightkeepers alternately live here, leaving three on watch at Yebosi, and a system of signals is arranged between the relief station and the lighthouse.

Satanomisaki (Chichakoff), the most southerly point of Japan, is the headland which vessels coming from the China seas generally make first. The headland is lofty and precipitous, and is covered with thick brushwood; but no site could be found on it for a lighthouse, to serve all the intended purposes. Directly off the point, however, there are two small islands, the outside one of which is about 300 yards distant from the mainland and 180 feet high. The point is exposed to the full strength of the Japan stream, which not unfrequently attains a speed of 3 or 4 miles an hour. This causes a constant disturbance in the sea, and between the outside island and the mainland there is generally a boiling surge. The island is pinnacle-shaped, and its summit had to be lowered for nearly 40 feet, before sufficient space could be obtained for the lighthouse tower. The dwellings for the lightkeepers were erected on the mainland. Owing to the disturbance in the sea caused by the currents, communication between the dwellings and the lighthouse was difficult. A wire rope was originally stretched across, first to the middle island and thence to the lighthouse, along which a cage was propelled by friction pulleys worked by a handle in the cage. This was used as a means of transport for men and materials for several years, but owing to a disinclination of the lightkeepers to use it, caused by nervousness from being suspended at so great a height, it was eventually abandoned. Communication is now carried on by boats, when the water is sufficiently smooth to enable a landing to be made. The tower is of iron, and is 17 feet 9 inches high to the sole-plate of the lantern. It is hexagonal, 24 feet in extreme width at its base and 16 feet at its summit. The lower floor of the tower is set apart as a sleeping and living room for the lightkeepers stationed on the rock, and space is also provided to enable them to keep sufficient provisions to last until relief arrives from the mainland. The other floor of the tower is used for the purposes of the light.

The highest lighthouses are the brick lighthouse at Noshima, 85 feet high to the sole-plate of the lantern; the brick lighthouse at Inuboye, 80 feet high to the sole-plate of the iron parapet; the brick lighthouse at Siriyasaki, 82 feet 6 inches high to the sole-plate of the iron parapet; the wooden lighthouse at Shiwomisaki, 61 feet high to the sole of the lantern; and the stone lighthouse at Kadoshima (Plate 2, Fig. 3), 74 feet 7 inches high to the sole of the iron parapet.

The lightships were built, under the superintendence of the

Author, by native workmen. They are 70 feet 8 inches long between the perpendiculars, 18 feet 10 inches breadth of beam, 9 feet 2 inches deep from the deck to the top of the limbers, and are 130 tons burthen by builders' measurement. They are fitted with two decks, having a clear headway of 6 feet 6 inches between them. The lower one, running the whole length of the ship, is used as a berth-deck for the accommodation of the captain and crew. Below are the water-tanks, cable-lockers, ballast space, fuel and lumber stores. The keel, stern-post, stem, timbers, &c., are of keaki. The outside planking is also of keaki, 2 inches thick. The upper deck is of shinoki, 2½ inches thick; and the lower deck of sugi, or cedar, 2 inches thick. The vessels are fastened with ¾-inch copper bolts, and are sheathed with Muntz metal, weighing 26 oz. to the superficial foot, up to 2 feet above the water-line. They have two masts. The lantern, containing the light apparatus, is hoisted on the mainmast, which is 16 inches in diameter, and 40 feet high. They are flat on the floors, and are made with a bow specially adapted for riding in a heavy sea after the model of the Trinity light-vessels. They are moored with two 30-cwt. anchors, having 60 fathoms of 1½-inch standard cable on each.

The beacons, built on rocks only awash at low water, are constructed of solid ashlar masonry, the stones in each course being made to radiate from the centre. They are 8 feet in diameter at the base, and 4 feet at the summit; the height being 20 feet. In the first six courses the stones are secured by hard wood joggles; and the coping stones, or the balls which surmount the structure, are secured by a 2-inch bolt, which goes through 7 feet of the masonry.

The buoys were constructed of iron, likewise from the designs of the Author, by native workmen. They are of the ordinary shapes of nun, can, and hollow-bottomed buoys. Their moorings consist of two lengths, of from 15 to 30 fathoms, of ¾-inch cable, attached to two 5-cwt. anchors, one being placed up, and the other down stream. The anchors made by Japanese workmen are very efficient.

The glass-work of the apparatus for the different lights has been manufactured from the designs of Messrs. D. & T. Stevenson, by Messrs. Chance Brothers, Birmingham; Messrs. Sautter, Lemonier, and Co., and Messrs. Barbier and Fenestre, Paris. The lanterns, machines, reflectors, reflector-frames, &c., have been principally executed by Messrs. Milne and Son, and Messrs. Dove and Co. of Edinburgh.

Besides the aseismatic tables in the first lighthouses, the Messrs. Stevenson were induced to adopt a species of apparatus of as unfragile a nature as possible. They had fears that the sudden shocks, to which the lighthouses would be exposed, might derange the delicate glass-work in a dioptric apparatus, and they consequently decided to use metallic reflectors. These are arranged on frames secured to the aseismatic tables, and they were supplied for all the lights included in the original order. In addition to this, the lanterns were made as low as possible, and of an increased strength. The daylight height of these is 6 feet only; whereas the ordinary height of first order lanterns is 9 feet 9 inches.

While there can be little doubt that these measures tend to lessen the risk of fracture or derangement from earthquakes; and while the use of reflectors offers this additional advantage, that in case of the partial destruction of the apparatus, the light can be at once reinstated by keeping in stock a few spare reflectors, lamps, &c., other considerations render the adoption of these a matter of doubtful expediency. The whole country is subject to severe earthquakes; but that any single lighthouse should experience a shock of such severity as would derange its optical apparatus, is a remote contingency, and not likely to occur more than once in a century. It may further be assumed, that such a shock as would fracture an apparatus would, in all probability, prove destructive to the lighthouse tower in which it was placed. After the occurrence of such an earthquake, therefore, the permanent light must necessarily be extinguished until steps were taken to replace both the tower and the apparatus, and the accomplishment of this would, under any circumstances, occupy some time.

The Author accordingly thought it unnecessary to adopt extraordinary precautions in regard to the lantern or apparatus, when he felt it to be impracticable to use these in the construction of the towers; and the adoption of a reflector apparatus, and a lantern of small dimensions, offers many disadvantages.

1. The cost of a reflector apparatus, such as was sent to Japan, is somewhat more than that of a dioptric apparatus.

2. The polishing of reflectors requires greater skill and attention than the cleaning of glass, and the liability to damage during the process is greater. This is an important consideration in a country where the lightkeepers are only partially trained, and of not very attentive habits.

3. The consumption of oil in reflector lights is about 25 per cent. higher than in dioptric lights in relation to the amount of light produced; and the consumption of wicks and lamp-chimneys is also greater.

4. The excessive heat given out by the flames in reflector lights impairs the ventilation of the lantern. In the first order lights, twenty-eight reflectors are used to transmit an equal light to every part of the horizon; and as in each there is an Argand burner, the accumulated heat from these renders a proper ventilation of the lantern a difficult matter. This is specially noticeable on fine summer nights.

5. The lowness of the lantern confines the air-space, and tends to increase the heat and to check ventilation.

The Author therefore concluded that, while the risk of adopting dioptric apparatus was doubtful, its advantages over reflector lights were important; and he recommended that, for future lights, the ordinary dioptric apparatus, and the size of lantern in use in Europe, should be adopted. His recommendations on this point were finally approved and acted upon.

All the lanterns have been formed with diagonal astragals, similar to those adopted in the Northern Lights. They have been fitted with a cast-iron cornice-plate and sole-plate, to which the astragals, made of gun-metal, are screwed. The roof is dome-shaped, and is double; the inner casing being made of No. 16 B.W.G. sheet copper, and the outer of No. 14 B.W.G. sheet copper. The ventilator on the top of the dome is of the same design as that used on the Northern Lights, having a couple of funnels, each covered by caps, surmounted by a hemisphere of copper, through which arrangement the heated air finds exit. Storm-panes are supplied to each lantern, and are provided with clip screws by which they can be attached to the lantern astragals, so that on the breakage of a pane they can be screwed in their places without delay.

Stevenson's holophotalized reflectors, adopted in the catoptric lights, are parabolic, 21 inches in diameter at their mouths, with a spherical mirror at the back, and a lens in front of the flames. The glass-work consists of a central lens, and four totally reflecting zones. These are made so that no light from the flame shall escape without being acted upon. The frames on which the reflectors are grouped have been constructed to carry two tiers of reflectors: those lights which show all round the horizon have fourteen on each tier. In fixed lights they are so arranged, that the axes of the apparatus on the upper tier fall midway between those of the lower tier; in this way insuring an equable light in every azimuth. In revolving lights the frames are made with from six to eight faces, and two or more reflectors are placed on each face. The frames are of wrought iron, and are fitted with brackets on which the reflectors rest, and which allow of the fourteen reflectors in fixed lights being placed round the circle.

The lightship lanterns surround the mainmast of the vessel. They are octagonal in shape, and are 5 feet in width from glass to glass, the daylight height being 2 feet 2½ inches. Ventilation is procured by eight tubes, on the roof, 3 inches in diameter, which are surmounted by a hemispherical cowl. There are also in the cornice-plate seventy-two holes, each 1 inch in diameter, and over these are sliding plates, with corresponding holes, while there are eight ventilators in the floor of the lantern. There are eight sets of apparatus in the lantern, each of which consists of a glass catadioptric apparatus in front of the flame, with a silvered spherical reflector behind it. The radius of the glass apparatus is 75 millimètres, and is made to embrace 180°. It consists of a central refracting belt, with one prismatic ring above and below, and above and below the prismatic rings are two catadioptric prisms. The spherical reflectors are 8 inches in diameter, and are of silvered copper. The apparatus is hung in swinging gimbals, which allows of its remaining plumb during any movement of the ship under 30°.

The dioptric apparatus, adopted in the later lights, is the ordinary Fresnel design, with all recent improvements. The first order fixed apparatus has a cylindric refractor, consisting of a central belt, with six prisms above and below it. There are eighteen catadioptric zones above the refractor and eight below it. The glass-work was put to the usual optical tests, by Messrs. Stevenson, before being taken off the manufacturer's hands.

The oil burned in the lighthouses has been, up to within a recent period, imported from China. The manufacture of oil in Japan is limited, and although some Japanese oils are good, no dependence can be placed upon getting a regular supply of any of these. One oil from China, procured from a nut, is a good burning oil, but its supply was uncertain, and its price often rose so high as to make its use almost prohibitive. Another Chinese oil, made from beans, is always to be had in large quantities, and its price is moderate, but its quality is variable, and under the most favourable circumstances, it does not give satisfactory photometrical results. The supply of vegetable oils of the necessary quality being therefore doubtful, the Author deemed it advisable to recommend the adoption of mineral oils, and sanction was given to this in November 1872.

The burner invented by Captain Doty was selected. It is claimed for this burner, that it consumes a smaller quantity of mineral oil than the ordinary Argand burner does of vegetable oil, and that it produces a more powerful light;—that, "volume for volume, mineral oil is superior to colza oil to the extent of one-fourth more light in the first order lamps, two-fifths more in the second, one-half more in the third, and four-fifths more in the fourth order lamps;"—that the flames are more easily attended to, and the standard heights of these more readily obtained;—that mineral oil is not affected by cold, and that it may be used without danger in hot weather;—that the same lamp-chimneys and wicks can be employed for burning mineral oil as for vegetable oil, and that the burners can be applied with ease to all existing lamps. Practical experience, afforded by the working of the Doty burner in Japan, bears out, to a great extent, these statements. The best result attained in an ordinary Argand lamp, with the oils formerly used, was a flame equal to ten standard sperm candles. There was always a difficulty in maintaining this standard, snuffing and trimming being necessary once, or sometimes twice, during the night. The Doty burner, in the same lamp, gives a flame equal to eighteen or twenty candles, which burns steadily, and generally without requiring any touching during the longest nights. The consumption of oil depends very much upon the skill of the lightkeeper. It is quite possible to cause an unnecessary consumption by the want of proper regulation of the ventilation in the lantern. The consumption has, therefore, varied considerably; but this difference will no doubt disappear as the lightkeepers get more accustomed to the use of the oil. The fitting of the Doty burner on the existing lamps was carried out with little expense or trouble. But the flame produced by a Doty burner, while exceedingly pure and brilliant, emits a much greater heat than that from a vegetable oil flame. The breakage of lamp-chimneys has on this account increased considerably. In the reflector lights of the first order, where there are in some cases as many as twenty-eight lamps in one lantern, the heat is, in certain states of the weather, very high and productive of great inconvenience. It is no uncommon thing for the temperature inside the lantern to be 130° Fahr., when that outside is 85°. This is the only real objection to the Doty burner in Japan, but there can be little doubt that it is capable of remedy by increased ventilation.

The mineral oil principally used up to the present time has been Young and Co.'s paraffin oil. It was procured direct from the works at Bathgate, and was imported in iron drums, each containing 5 gallons. Its cost, delivered in Yokohama, including all charges, was 75 cents per gallon. The specific gravity of this oil is 810, water being 1,000, and it does not emit any inflammable vapour until heated up to 145° or 150° Fahr.

Different samples of American kerosene have been tried. Its market price in Yokohama varies from 45 to 60 cents per gallon; but no specimens have been found of sufficiently good quality to warrant its use in the lighthouses. Its specific gravity ranges from 760 to 790, and many specimens had a flashing point as low as 80°. The best which was tried gave 120° as its flashing point, but it was consumed in a Doty burner, at 25 per cent. greater rapidity than the paraffin oil, and is altogether unreliable.

Petroleum exists in Japan in large quantities, and many wells have been sunk by the natives in different parts of the country. But no measures have yet been taken for carrying out the necessary refining processes, so as to enable it to be used either for domestic or for lighthouse purposes.

The principal office of the Lighthouse Department is at Yokohama. The workshops, store-rooms, &c., are erected on a space of about 4 acres of ground, and form a complete establishment, where the whole work required in the construction and maintenance of the lighthouses, lightships, and buoys, has been carried on. The yard is on the seashore, and is provided with a stone jetty, alongside of which boats can lie. On this is placed a crane capable of lifting 5 tons, and a line of rail runs from it to the different store-rooms.

In the yard there is an experimental lighthouse, a brick building, 20 feet square and 40 feet high. There are three floors, the lower one being used for testing oils, trying the power of flames, repairing or readjusting apparatus, or doing such other experimental work as may be required. The second and third floors are used for the purposes of the lighthouse. The lantern was entirely constructed in the lighthouse yard, and is of the ordinary size for first order lanterns. The different floors are fitted with trap-doors, sufficiently large for the largest apparatus to pass without being taken to pieces. The principal object of the lighthouse is to afford means for furnishing a preparatory training to young Japanese lightkeepers previous to their being sent to the regular lighthouse stations. It is also used for examining apparatus, which during its voyage from England may have got shaken out of adjustment, or have been otherwise damaged. The mineral oil store, built of concrete, with walls 2 feet thick, and an arched roof of brick, is capable of containing 30,000 gallons of oil, in the boxes in which it usually comes from England. There is also a vegetable oil refinery, with the boilers, agitators, and vessels necessary for settling and filtering the oil. Everything connected with the lighthouses, with the exception of the optical apparatus and lanterns, has been constructed in the establishment. The two lightships were built, fitted out, and entirely completed in the yard; twenty-two buoys were made, and the iron and wooden lighthouses were fitted previous to being sent to their destinations.

The whole work has been carried on with the help of two assistant engineers, Mr. James MacRitchie, Assoc. Inst. C.E., and Mr. S. Fisher. One secretary and two clerks were also attached to the establishment. The other Europeans engaged in the service at different times were: one superintendent blacksmith, two inspecting and repairing artisans for the apparatus, one plumber and coppersmith, one shipwright, four masons, and fifteen lightkeepers.

The Japanese staff is presided over by a commissioner, with two assistant-commissioners acting under him. These are granted certain powers by the Public Works Department of the Government, and they are supposed to work in concert with the chief Europeans in the office. But, in point of fact, they are vested with the supreme control, and the Europeans have little or no authority. Under the commissioners there is a staff of fifty-three Japanese officials, who are divided among four departments, viz.: the secretary's, the accountant's, the building or construction, and the storekeeper's departments. The organisation of the office was arranged so as to serve the peculiar requirements of the service. The Author compiled, from English, French, and American sources, one book of instructions for lightkeepers and another for repairing artisans. These were translated into Japanese, and are closely adhered to. The former gives minute directions regarding every process in connection with the lights, and orders meteorological records to be kept at each station. The latter explains the adjustments necessary in the apparatus, and the manner in which repairs are to be carried out.

The European lightkeepers are distributed among the most important ocean lighthouses, but their numbers are being gradually reduced, as the Japanese become more expert and efficient. The Japanese lightkeepers number one hundred and two, but only a few of them are sufficiently advanced to have the entire charge of a light, the remainder acting as assistants under the Europeans. There are generally four Japanese at each station under the European, one of whom is principal, the remaining three being pupils in the course of training. The European lightkeepers have authority to demand obedience from the Japanese in any matter connected with the keeping of the lights, or the general good order of the station, but they have no further control over them; and the execution of repairs, procuring stores, or the making of any payments is done through the Japanese principal lightkeeper. The Europeans are specially directed to be attentive in instructing the Japanese lightkeepers, and rewards are held out to those who succeed in training the most efficient men.

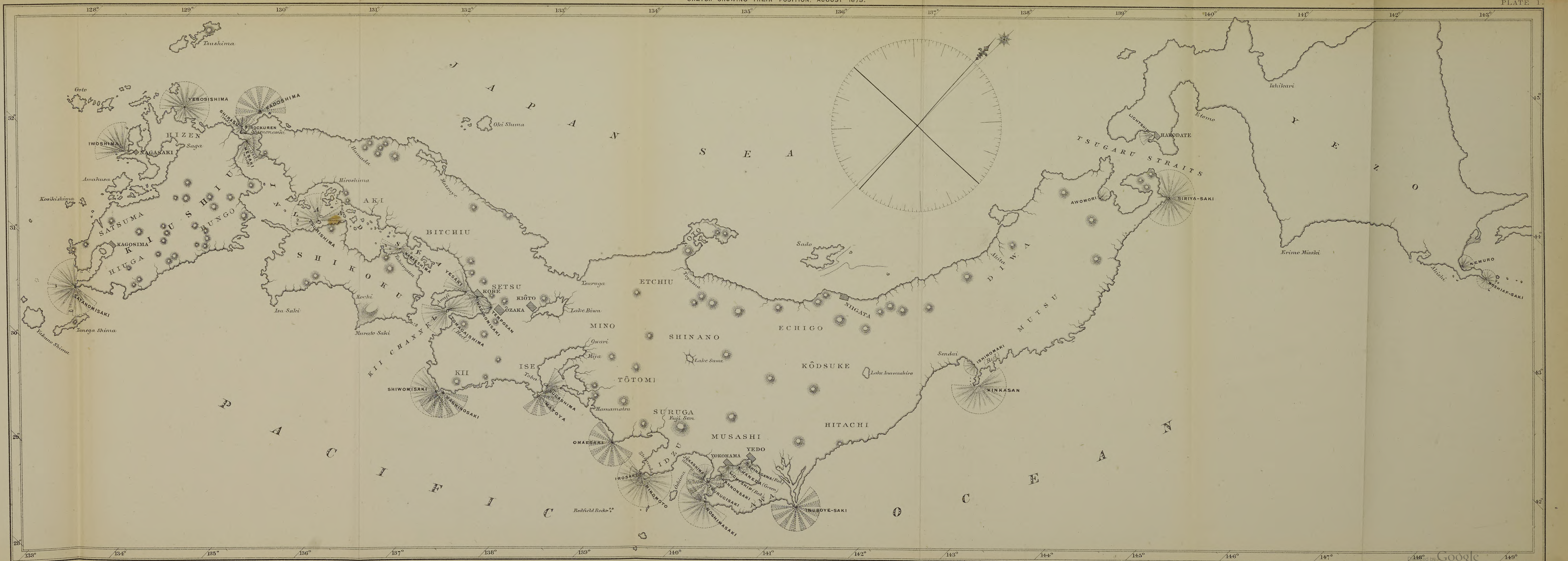
Each lighthouse is inspected, on an average, three times every year by one of the Japanese commissioners, accompanied by one of the engineers. The only ready means of communication with most of the lighthouses is by sea; and the vessel procured for carrying on the work of inspection is a paddle-wheel steamship of 489 tons register and 370 nominal HP. She is easily handled in confined harbours, of great power, and capable of steaming out of danger under any circumstances, with a capacious deck for buoys, and the necessary passenger and cargo accommodation. She is commanded and officered by Europeans, but her crew consists of Japanese only.

Owing to the manner in which the Japanese keep accounts, and their desire to have the whole control of the expenditure, the Author, notwithstanding the utmost efforts, has failed to preserve a correct record of the cost of the works. For the first year a system of certificates was instituted, by means of which he had a check upon all moneys paid; but he soon discovered that many payments were made by the Japanese officials without any certificate, and the practice had to be abandoned as useless. He has further been in partial ignorance of the prices paid for material and labour. The statement, in Appendix II., of the money expended in the construction and maintenance, of each lighthouse, has chiefly been supplied by the Japanese officials.

The Author arrived in Japan just at the completion of the civil war, which revolutionised the country and gave Europeans a more secure footing in it. He then found the various Government departments in a disorganised state. The lighthouse work was transferred from one to another, and at various times was in charge of about eight or ten different sets of officials. It so became difficult to organise the service, or to arrange or enforce any rules or regulations. At the time of his arrival no artisans were acquainted with anything beyond the slight and unimportant work customary

THE JAPAN LIGHTS,
SKETCH SHOWING THEIR POSITION, AUGUST 1875.

PLATE 1.


Taushima
Goto
YEBOSISHIMA
KADOSHIMA
SHIRASU (red)
ROCKUREN
Shimonoseki
HESAKI (red) (white)
IWOSHIMA
NAGASAKI
HIZEN
Saga
Amakusa
Kosikishima
SATSUMA
KIUSHIU
BUNGO
KAGOSIMA
HIUGA
SATANOMISAKI
Tanega Shima
Yakuno Shima
Oki Shima
JAPAN SEA
Hiroshima
AKI
INLAND SEA
TSURISHIMA
SHIKOKU
BITCHIU
NABAESHIMA
Takamatsu
YESAKI
Koghi
Isa Saki
Murato Saki
Awaji
KOBE
SETSU
WADANOMISAKI
TOMAGAISHIMA (Red)
TEMPOSAN
ÔZAKA
KIÔTO
Lake Biwa
Tsuruga
MINO
KII CHANNEL
KII
SHIWOMISAKI
KASHINOSAKI
ISE
Toba
SUGASHIMA
MATOYA
Owari
Miya
TÔTOMI
Hamamatsu
ETCHIU
SHINANO
Lake Suwa
Sado
ECHIGO
NIGATA
KÔDSUKE
Lake Inawashiro
SURUGA
Fuji San
OMAESAKI
IDZU
Shimoda
IROSAKI
MIKOMOTO
Ôshima
Redfield Rocks
MUSASHI
YEDO
YOKOHAMA
JÔKASHIMA (Green)
SHINAGAWA (Red)
HANEDA (Green)
LIGHTSHIP (Red)
KANNONSAKI
TSURUGISAKI
NOSHIMASAKI
AWA
INUBOYE-SAKI
HITACHI
PACIFIC OCEAN
Sendai
ISHINOMAKI (Red)
KINKASAN
MUTSU
DIWA
Akita
AWOMORI
SIRIYA-SAKI
TSUGARU STRAITS
LIGHTSHIP
HAKODATE
Etomo
Ishikari
YEZO
Erimo Misaki
Akishi
NEMURO
NOSHIAF-SAKI

R. HENRY BRUNTON, DEL^T.

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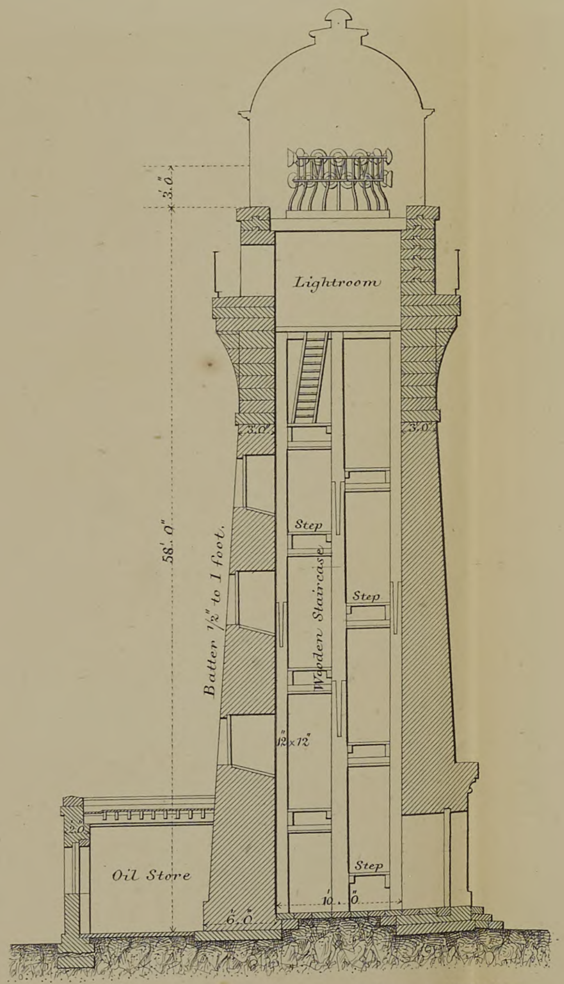
THOS KELL, LITH 40, KING ST COVENT GARDEN.

41', 10½"
3.0"

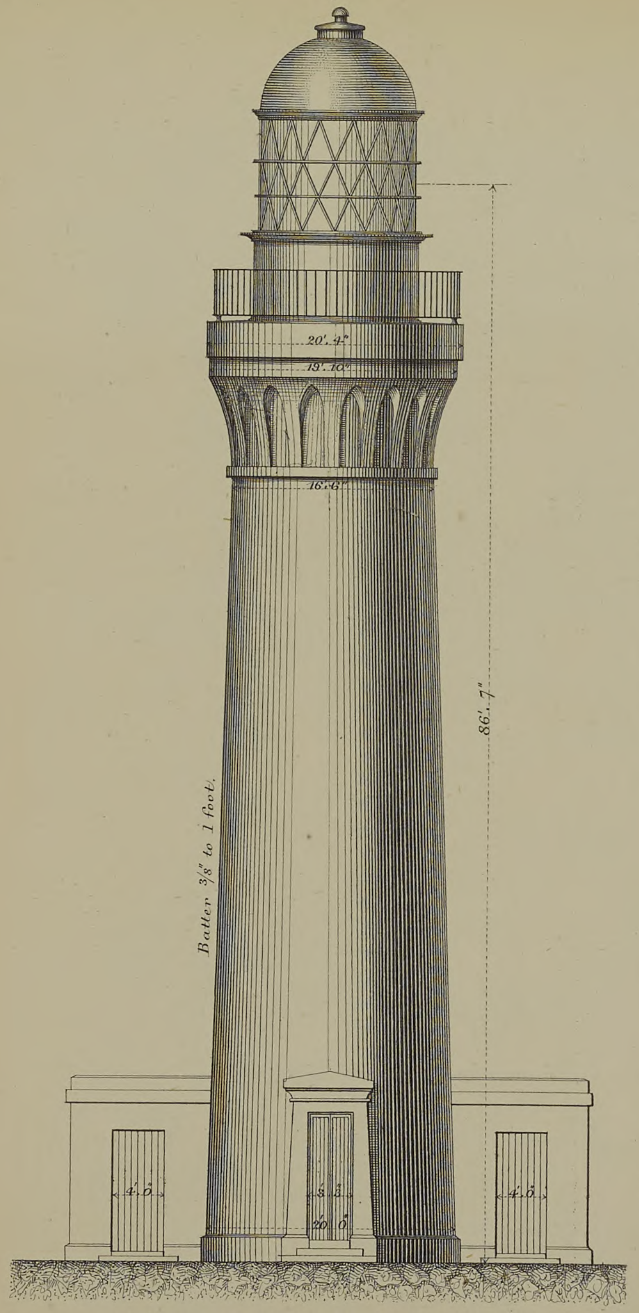
THE JAPAN LIGHTS.

Fig: 2.


Lightroom.
Wooden Staircase
Step
Batter ½ to 1 foot.
56'.0"
Oil Store

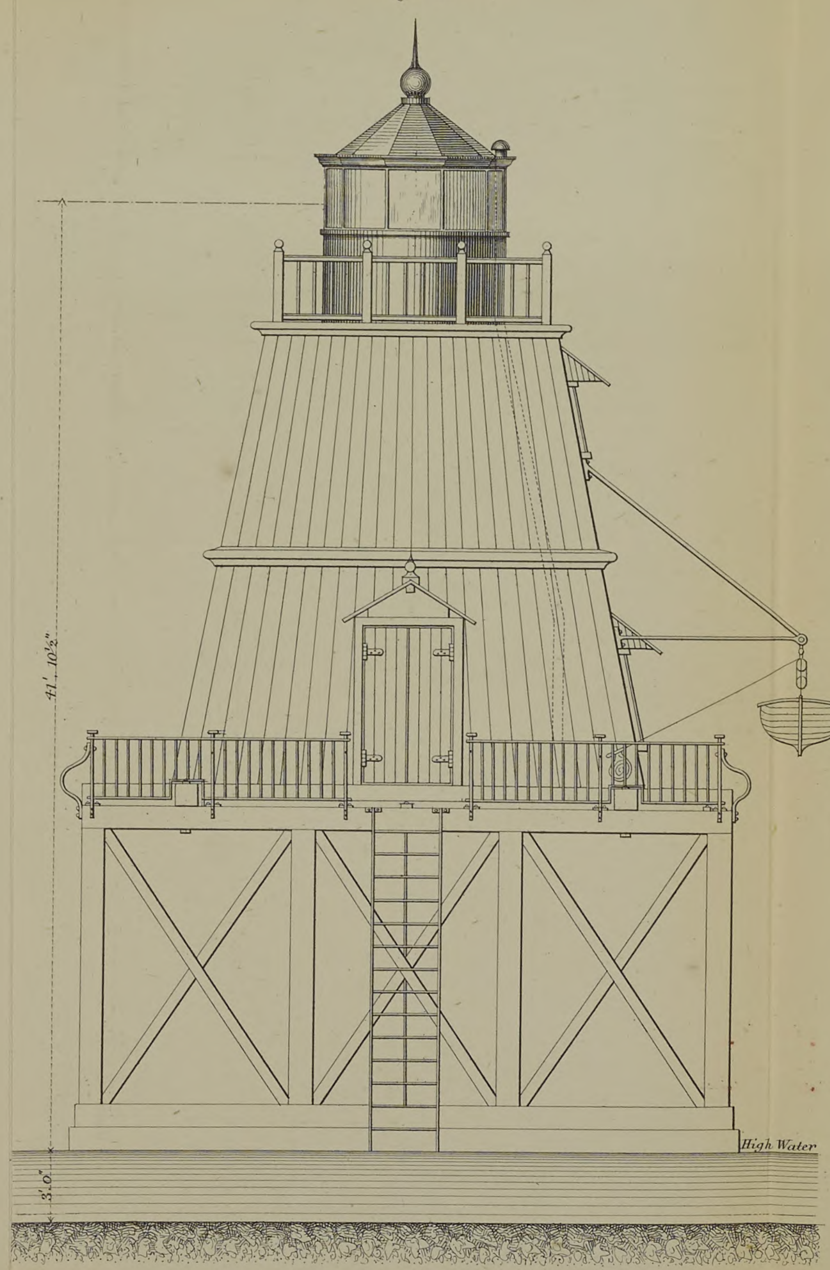
SECTION OF MIKOMOTO STONE LIGHTHOUSE.

Fig: 3.


Batter ⅜ to 1 foot.
86'.7"

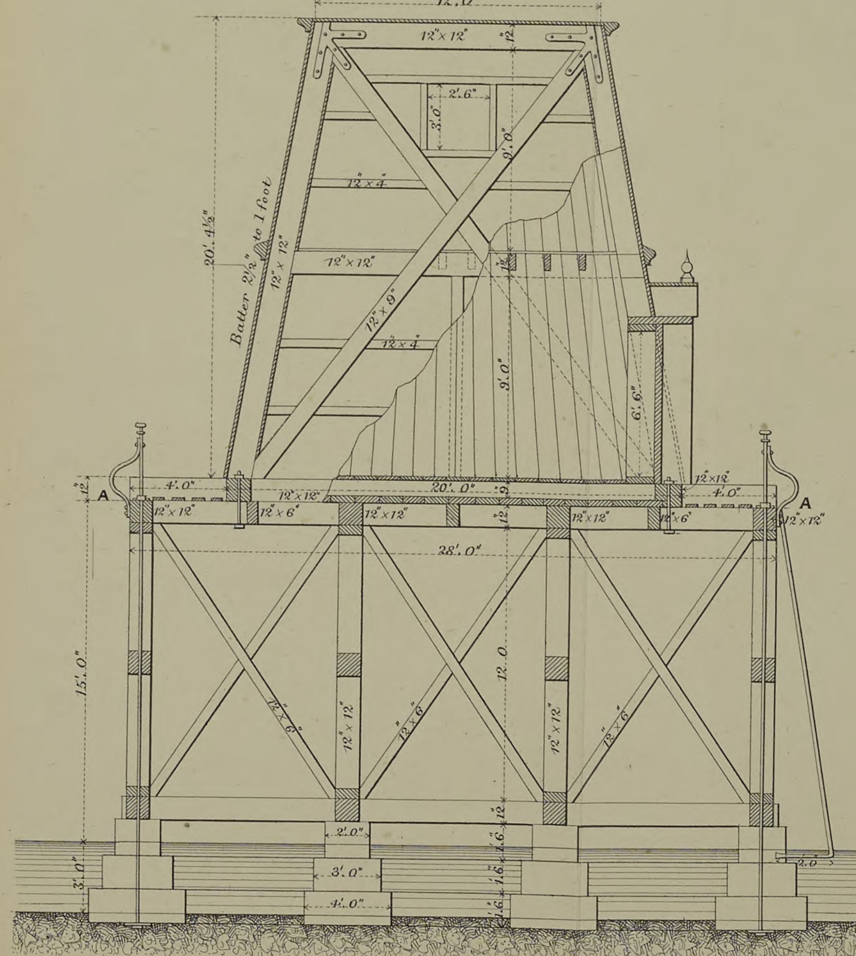
ELEVATION OF KADOSHIMA STONE LIGHTHOUSE.

Fig: 4.


41'.10½"
High Water

ELEVATION.

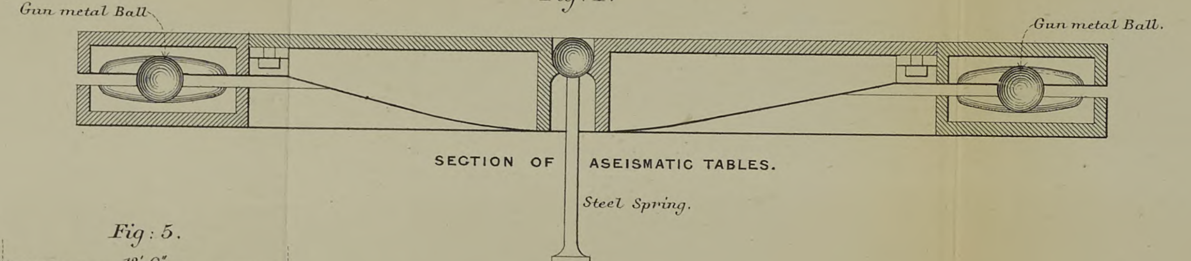
Fig: 5.



SECTION.

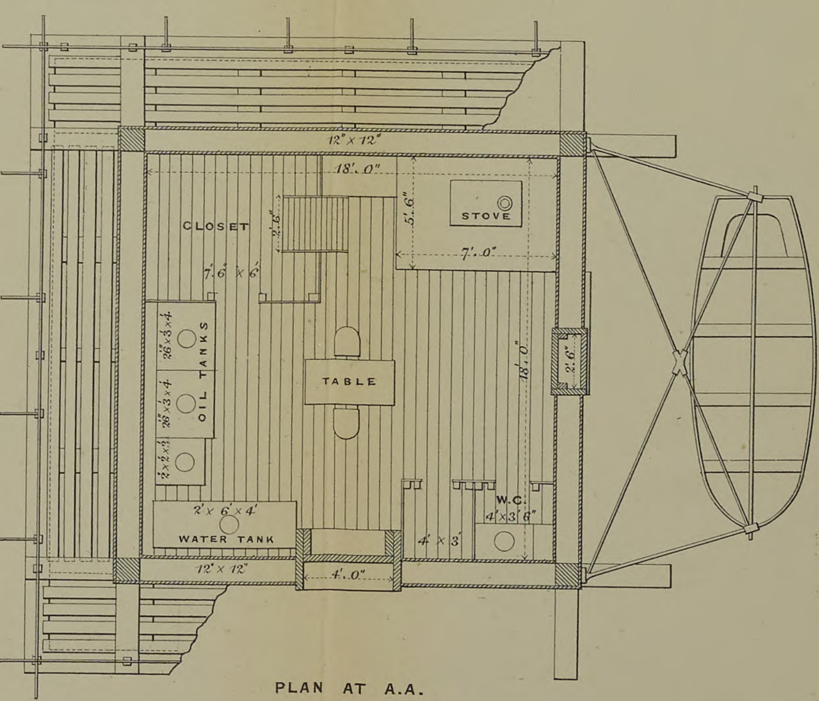
SHIRASU WOODEN LIGHTHOUSE.

Fig: 1.


Gun metal Ball.
Gun metal Ball.
Steel Spring.

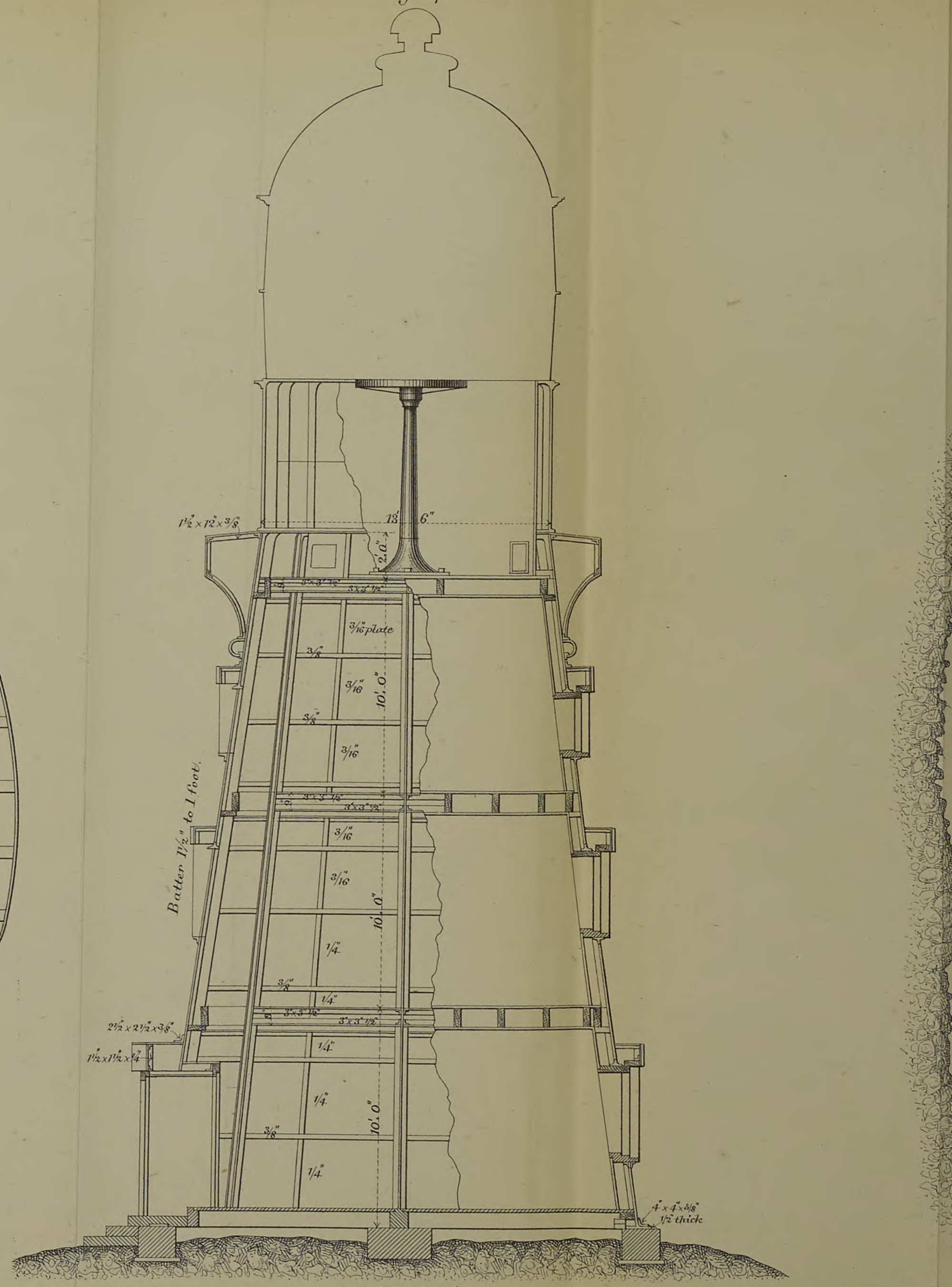
SECTION OF ASEISMATIC TABLES.

Fig: 6.


CLOSET
STOVE
TABLE
OIL TANKS
WATER TANK
W.C.

PLAN AT A.A.

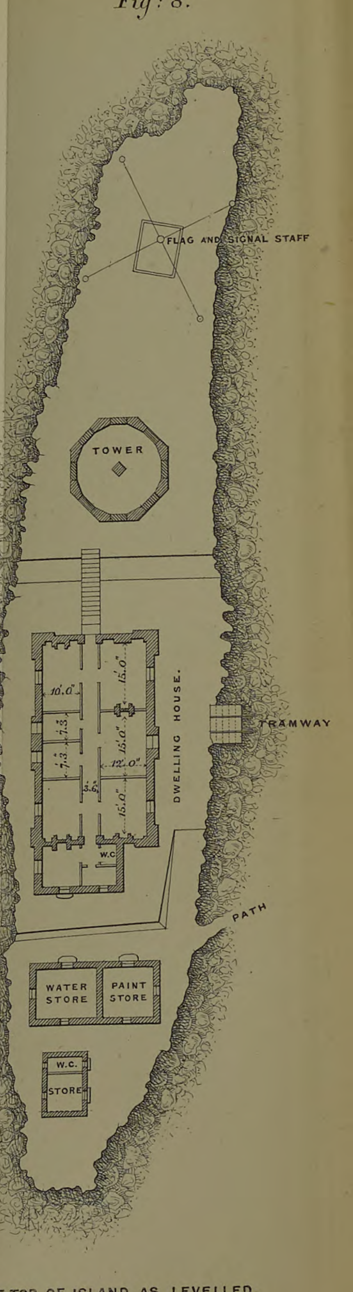
Fig: 7.


Batter 2½ to 1 foot.

SECTION.

YEBOSI-SHIMA IRON LIGHTHOUSE.

Fig: 8.


FLAG AND SIGNAL STAFF
TOWER
DWELLING HOUSE
TRAMWAY
PATH
WATER STORE
PAINT STORE
W.C.
STORES

PLAN OF TOP OF ISLAND AS LEVELLED.

R. HENRY BRUNTON, DELT

THOS KELL, LITH. 40, KING ST COVENT GARDEN.

in the country. Carpenters were skilful in the use of their tools, but masons, bricklayers, and blacksmiths were almost unknown. Men had therefore to be taught each of those trades, and the works had to be carefully watched during their progress. The staff of Europeans employed has been extremely small, but notwithstanding the difficulties surrounding the prosecution of the works, each lighthouse is well finished. There have been no signs of failure of any importance, and the earthquakes which have occurred since their erection—one or two were severe—have had no visible effect upon them.

The Author has received most flattering assurances of the high appreciation in which the lights are held by the nautical men who frequent the coasts of Japan; and great credit is due to the Japanese Government for the liberal manner in which it has prosecuted the work.

The Paper is accompanied by a series of drawings, from which Plates 1 and 2 have been compiled.

APPENDIX I.

LIST of LIGHTHOUSES, LIGHTSHIPS, BUOYS and BEACONS on the COAST of JAPAN.

LIGHTHOUSES.

1. Shinagawa . .	Dioptric.	Red.	Fixed.	5th Order.
2. Yokohama Harbour	do.	do.	do.	Staff light.
3. Haneda . . .	do.	Green.	do.	4th Order.
4. Kannonsaki . .	do.	White and Red.	do.	3rd do.
5. Tsurugisaki . .	Catoptric.	do.	Flashing.	2nd do.
6. Noshimasaki . .	Dioptric.	White.	Fixed.	1st do.
7. Inuboyesaki . .	do.	do.	Revolving.	1st do.
8. Kinkasan . . .	do.	do.	Fixed.	1st do.
9. Siriyasaki . . .	do.	do.	do.	2nd do.
10. Awomori . . .	do.	Red.	do.	Staff light.
11. Ishinomaki . .	do.	White.	do.	do.
12. Noshiaf . . .	do.	do.	do.	do.
13. Nemuro . . .	do.	Red.	do.	do.
14. Jôkashima. . .	do.	White.	do.	5th Order.
15. Mikomoto (Plate 2, Fig. 2) . . .	Catoptric.	White and Red.	do.	1st do.
16. Irôsaki. . . .	do.	Red.	do.	6th do.
17. Omaesaki . . .	Dioptric.	White.	Revolving.	1st do.
18. Sugashima. . .	do.	do.	Fixed.	4th do.
19. Matoya . . .	do.	do.	Revolving.	4th do.
20. Kashinosaki . .	Catoptric.	do.	do.	2nd do.
21. Shiwomisaki . .	do.	do.	Fixed.	1st do.
22. Tomagaishima .	Dioptric.	do.	do.	3rd do.
23. Temposan . . .	do.	do.	do.	4th do.
24. Wadanomisaki .	do.	Red.	do.	4th do.
25. Yesaki	Catoptric.	White.	do.	1st do.
26. Nabeshima . .	Dioptric.	do.	do.	3rd do.
27. Tsurishima . .	do.	do.	do.	do.
28. Hesaki . . .	do.	White and Red.	do.	4th Order.
29. Rockuren . . .	do.	White.	do.	do.
30. Kadoshima (Plate 2, Fig. 3) . . .	do.	do.	Flashing.	1st Order.
31. Shirasu (Plate 2, Figs. 4, 5, and 6).	do.	Red.	Fixed.	5th do.
32. Yebosishima (Plate 2, Figs. 7 and 8)	do.	White.	do.	2nd do.
33. Iwoshima . . .	Catoptric.	do.	do.	1st do.
34. Satanomisaki . .	do.	do.	do.	do.

(*Continued on page* 24.)

APPENDIX II.

EXPENDITURE INCURRED by the LIGHTHOUSE DEPARTMENT from the DATE of its ESTABLISHMENT, August 1868, to the end of 1875.

Name of Light.	Date of Commencement.	Date of Completion.	Height of Tower to centre of Lantern.	Material.	Cost.
			Feet.		Dollars.
1. Shinagawa	Feb. 1873	Apr. 1873	19	Brick	2,054
2. Yokohama Harbour	Jan. 1874	Mar. 1874	40	Wood	245
3. Haneda	Mar. 1874	Mar. 1875	55	Iron	14,000
4. Kannonsaki	Oct. 1868	Dec. 1868	40	Brick	8,182
5. Tsurugisaki	Mar. 1870	Mar. 1871	25	Stone	34,444
6. Noshimasaki	Mar. 1869	Dec. 1870	99	Brick	22,599
7. Inuboyesaki	Feb. 1872	Nov. 1874	90	do.	44,825
8. Kinkasan	Mar. 1874	..	24	Stone	45,100
9. Siriyasaki	June 1873	..	92	Brick	61,300
10. Awomori	July 1874	Nov. 1874	40	Wood	424
11. Ishinomaki	Dec. 1873	Feb. 1874	40	do.	424
12. Noshiaf	June 1872	Aug. 1872	31	do.	2,519
13. Nemuro	May 1872	Aug. 1872	40	do.	424
14. Jôkashima	July 1870	Sept. 1870	19½	Brick	2,090
15. Mikomoto	Apr. 1869	Jan. 1871	60	Stone	107,530
16. Irôsaki	July 1871	Oct. 1871	20	Wood	2,430
17. Omaesaki	June 1872	May 1874	57	Brick	33,340
18. Sugashima	Feb. 1872	July 1873	28½	do.	8,912
19. Matoya	Oct. 1871	Sept. 1872	36	Wood	13,023
20. Kashinosaki	Apr. 1869	Aug. 1870	15	Stone	40,229
21. Shiwomisaki	Apr. 1869	Oct. 1870	63	Wood	50,253
22. Tomagaishima	May 1870	July 1872	21	Stone	22,963
23. Temposan	Dec. 1870	May 1871	30	Wood	6,509
24. Wadanomisaki	Oct. 1870	May 1871	46	do.	13,517
25. Yesaki	May 1870	May 1871	15	Stone	28,119
26. Nabeshima	Dec. 1871	Feb. 1873	21	do.	7,919
27. Tsurishima	Oct. 1871	July 1873	21	do.	18,823
28. Hesaki	Dec. 1870	Apr. 1872	21	do.	20,204
29. Rockuren	Dec. 1870	Dec. 1871	25	do.	23,710
30. Kadoshima	Aug. 1873	..	87	do.	52,000
31. Shirasu	Mar. 1872	Mar. 1872	42	Wood	9,239
32. Yebosishima	Aug. 1873	Aug. 1875	44	Iron	69,400
33. Iwoshima	June 1869	Jan. 1872	23	do.	21,920
34. Satanomisaki	Jan. 1870	Dec. 1871	20	do.	66,838

(*Continued on page* 25.)

APPENDIX I.—*continued.*

LIGHTSHIPS.

35. Yokohama Bay	Catoptric.	Red.	Fixed.
36. Hakodate Harbour	do.	White.	do.

Of these thirty-six lights there are ten first-order, four second-order, four third-order, seven fourth-order, three fifth-order, one sixth-order, five staff lights, and two lightships.

BUOYS.

	Height in Feet.	Positions.
1. Can buoy	8	South of Yokohama Harbour.
2. Do. do.	8	North of do.
3. Do. do.	8	On Kawasaki Spit, Gulf of Yedo.
4. Do. do.	8	On do. do.
5. Nun do.	15	On Saratoga Spit, Gulf of Yedo.
6. Can do.	8	On Kanabuse, Shimonoseki Straits.
7. Do. do.	8	On Middle Ground, do.
8. Do. do.	8	On do. do.
9. Hollow-bottomed buoy	9	At Hikushima, do.
10. Do. do.	9	Do. do.
11. Do. do.	12	At Hiraiso, near Awaji Sima.
12. Do. do.	12	At Motoyama in Inland Sea.
13. Do. do.	12	North of Island of Ainoshima, west of Shimonoseki Straits.

BEACONS.

1. Stone beacon	20	On Manaita Rock, Shimonoseki Straits.
2. Do. do.	20	On Narusi Rock, do.
3. Do. do.	20	On Yodsibi Rock, do.

APPENDIX II.—*continued.*

LIGHTSHIPS.

					Dollars.
35. Yokohama Bay	Dec. 1868	Dec. 1869	..	Wood	29,645
36. Hakodate Harbour	May 1870	Apr. 1871	..	do.	29,260

BUOYS (including spare ones).

	Buoys.	Height in feet.	
Yokohama	3	8	2,379
Kawasaki	3	8	2,379
Saratoga Spit	2	15	3,320
Shimonoseki	5	8	3,965
Hikushima	3	9	2,370
Hiraiso	2	12	2,433
Motoyama	2	12	2,433
Ainoshima	2	12	2,433
Total	22		

BEACONS.

Manaita Narusi Yodsibi — Commenced April 1871. Completed September 1871	1,527
Lighthouse establishment, offices, and dwellings	66,237
Total cost of construction	$1,003,889
The purchase of the steam tender and her maintenance, the payments of all salaries to both European and Japanese officials, and various other miscellaneous expenses connected with the establishment amount to	1,050,000
The maintenance of the various lighthouses amounts to	189,000
Making a grand total of	$2,242,889
Or about £450,000 laid out on the lighthouse-work up to the end of the year 1875.	

[Messrs. STEVENSON,

Messrs. STEVENSON, having been intrusted by the Board of Trade to advise as to establishing a lighthouse system for the coasts of Japan, and to select and recommend for appointment engineers, foremen-mechanics, and trained lightkeepers to carry out their recommendations, desired, through the Secretary, to acknowledge the valuable services of Mr. Brunton, who had been selected for the office of Chief Engineer, in carrying out their designs. The Author of the Paper had not adverted to certain preliminary matters (probably because they occurred in 1867, before his appointment), which explained correctly what led to the adoption in the first instance of catadioptric instead of dioptric apparatus, and rendered it unnecessary to offer any observations on what the Author had said as to the comparative advantages of the dioptric and catadioptric systems of illumination, as to which lighthouse engineers did not differ in opinion.

These preliminary matters referred to the authenticated effects of earthquake shocks, to which attention had been drawn in all the reports sent from Japan to the British Government. In transmitting these reports to the Messrs. Stevenson, the Board of Trade specially requested them to consider in what way the anticipated injury to the apparatus could be ameliorated. The Elder Brethren of the Trinity House, who had also been consulted by the Board of Trade, suggested the employment of Holophotal reflectors as the safest apparatus that could, under the circumstances, be employed, a recommendation in which Messrs. Stevenson entirely concurred. As an additional safeguard they proposed the introduction of an 'aseismatic' arrangement. This, as applied to the apparatus, consisted of a slight alteration of the table on which the reflector frame and machine rest, at a cost of about £90 for each lighthouse.[1] Messrs. Stevenson were confirmed in their recommendation of this simple expedient from satisfactory experiments made in this country, which proved that violent shocks applied to the lower part of the table, failed to affect apparatus resting on it, so long as the aseismatic joint was in operation; but that whenever the table was screwed down, so as to form a rigid mass, the same shocks not only threw off the lamp-glasses, but in some cases extinguished the lights. Fig. 1 was a section in which the upper table bearing the holophotal reflectors was shown in hatched lines. This table rested on balls contained in cups formed in the upper and lower tables. Fig. 2 was a plan showing the points of support which, for ease of adjustment, had been made at three places dividing the circumference of the table into three equal arcs. The same arrangement had been proposed on a larger scale for the foundations of conical towers of plate iron. The vessel containing these towers was unfortunately wrecked, and no experience of their action existed.

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[1] *Vide* Transactions of the Royal Scottish Society of Arts, vol. vii., p. 557.

FIG. 1.

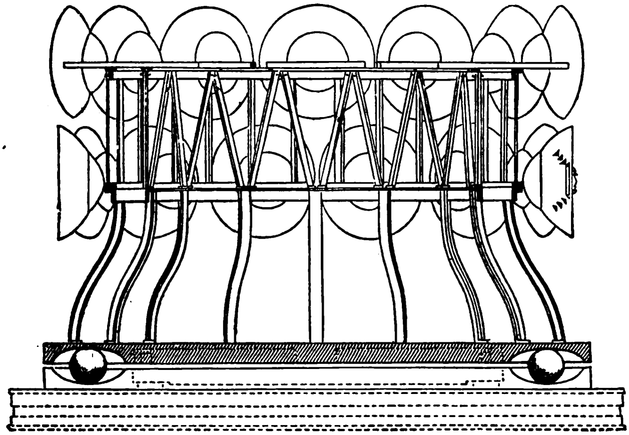
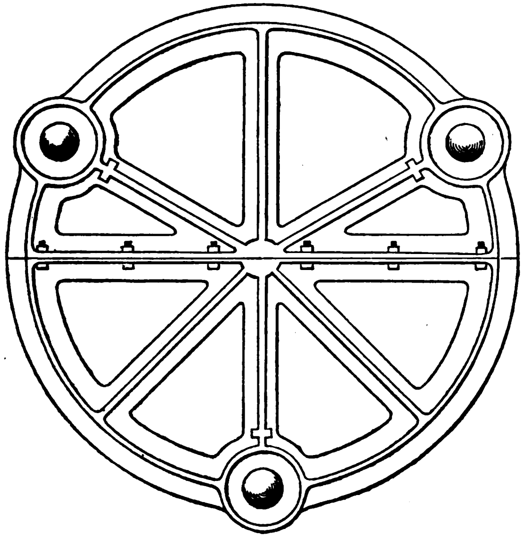


FIG. 2.



In further illustration of the subject, and particularly of what had been done in Japan, Messrs. Stevenson gave the following quotation from their Report to the Japanese Government made in June 1876, after the authorized works had been completed:[1] "In all of the documents," the report states, "which were submitted to us for consideration by the Board of Trade in 1867, whether from the French, American, or English authorities, great prominence was given to the prevalence of earthquakes, and their anticipated effects on the proposed lighthouse works. Captain Bullock, R.N., calls attention to the frequent volcanic shocks, and says, 'Engineering skill will be required to provide against them.' The French naval officers report that earthquakes, so frequent in Japan, 'would prevent the use of stone structures,' and the Trinity House report 'that perhaps the greatest difficulty of all will be found in the constant volcanic disturbances common in Japan.' To meet the difficulty which had been raised Mr. David Stevenson suggested the use of an 'aseismatic joint' in the table supporting the lighting apparatus, so contrived as to admit of a certain amount of horizontal movement taking place in the lighthouse without affecting the table on which the apparatus rests. This arrangement was proved on experimental trials made in this country to be successful, and it was introduced into the Japanese lighthouse apparatus. It would appear, however, that from some dislike to the unsteadiness of the apparatus during the process of cleaning, the aseismatic joint was secured so as to prevent it from acting; and, with the apparatus in this state, the only recorded earthquake which has affected any of the lights occurred at Segami, which is lighted by twenty-one holophotal reflectors. The shock had the effect of throwing the whole of the lamp-glasses out of their places, and disarranging the working of the machine, and the opportunity of testing the effect of the apparatus (as an amelioration of an earthquake shock) was thus lost. The experience obtained since the lighthouses were established has certainly gone to prove, that earthquake shocks have neither been so frequent nor severe as was represented; but it should be kept in view that such visitations are extremely uncertain, and may return at any time with renewed frequency and increased vigour. We should, therefore, suggest that if it be desirable to make the tables *less sensitive*, that this could easily be arranged without rendering them incapable of motion; or if it be considered desirable to screw up the tables while the apparatus is being cleaned, the screws should be made so as to be undone when that operation is completed, so that the responsibility for the action of the aseismatic apparatus should lie with the lightkeeper and not with the lighthouse authorities. The serious damage of any of the lighting apparatus by earthquake shocks, would entail undesirable responsibility if it should occur in a case where the aseismatic joint was found to have been permanently screwed up so as to prevent its acting."

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[1] Report to the Imperial Government of Japan, relative to lighthouses by D. and T. Stevenson, Civil Engineers, Edinburgh, 21 June, 1876.

Messrs. Stevenson had great pleasure in saying how much they were assisted by the valuable advice of Admiral Bedford, of the Board of Trade, in determining the positions and the characteristics of the most important of the sea lights; as well as in arranging the various details for giving the Japanese authorities the aid asked from the Government of this country in establishing their lighthouse system.

Mr. Douglass observed that, this being a case of the first lighting of a large extent of coast line, he should be glad to hear some explanation as to the large proportion of fixed to revolving or flashing lights. It was well known that revolving or flashing lights had an accumulative power from five to ten times greater than fixed lights, with the same consumption of oil; in other words, the annual cost for oil with a revolving or flashing light was from one-fifth to one-tenth of that of a fixed light of the same power. In first lighting a coast like Japan, an essential consideration would, therefore, seem to be to introduce as many revolving or flashing lights as possible, having due regard for the necessary distinctions to prevent one light being mistaken for another. The fixed light was considered to be the least distinctive, and should only be adopted where it was desirable to use coloured arcs to cover local dangers; but that appeared, from the Paper, to have been done only in three cases. Out of thirty-four lights only five were revolving. He thought that, as a provision against earthquakes, a light wrought iron, or wooden, structure would be preferable to one of stone. If the stone structure were low, as in some of the instances described, it might, no doubt, withstand a heavy shock; but, for a tower 80 or 100 feet high, a light iron structure, or one constructed of local timber, would have been less costly and more stable. If the earthquake shocks in Japan were as serious as had been represented, he should prefer the old catoptric revolving light. With this light the consumption of oil for the same amount of light would be greater than with a dioptric revolving light, but less than with a dioptric fixed light, while the first cost of the apparatus would be much less than that of a dioptric light, either revolving or fixed. With earthquake shocks these lights would be as safe as any building that an engineer could design. Evidence of this had been furnished by the forty-seven light-vessels in the service of the Trinity House. These vessels were all fitted on the catoptric system. In some collisions, the lantern and illuminating apparatus had fallen from the mast-head to the deck, a height of 30 feet, but in no instance had the apparatus been entirely destroyed. Under such circumstances, a dioptric apparatus would have been completely broken to pieces. A fixed catoptric apparatus was almost out of the question, except where very small arcs were required to be illuminated, because it was impossible to produce a well-defined cut between white and coloured arcs. It was stated in the Paper, that in the Doty burner, "volume for volume, mineral oil is superior to colza oil to the extent of one-fourth more light in the first order lamps, two-fifths more in the second, one-half more in the third, and four-fifths more in the fourth order lamps."[1] From his experience with the Trinity House lamps—with which the highest recorded photometric results with the greatest economy of working had been obtained—he had found that volume for volume there was no superiority in the best mineral oil over the best colza, but rather a small percentage in favour of colza; moreover, with colza oil these lamps burned almost uniformly for sixteen hours, with only the usual occasional regulation of the damper, but without any trimming of the wicks. The only known advantages of mineral oil over the best vegetable oils, including cocoa-nut, which was as good as colza, were its readiness of ignition, its flame more rapidly rising to the maximum power, and in some cases its low price—the present price in this country being about two-thirds that of colza.

Mr. W. Lloyd said, having had some experience in the construction of lofty buildings in countries liable to earthquakes, he thought there was a great deal more fear with regard to the effects of those shocks than was at all justified. He should like to give two instances that had come under his own observation bearing on the movable joint that had been proposed. As he understood it, this would allow of a limited horizontal movement, and of a free vertical movement. The first case was that of a church-tower in Mendoza, which had been almost entirely destroyed in the year 1861. Two storeys out of three remained after the earthquake. The lower storey was more or less intact, except that there was a large crack in it. The upper storey was entirely destroyed;

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[1] *Ante*, p. 17.

but the middle storey, by some horizontal movement, was turned round nearly one-half upon the lower storey, so that the angles of the upper storey corresponded more or less with the centre of the side of the lower storey. That showed an amount of horizontal movement which would be dangerous with a joint of the description proposed. With regard to the vertical movement in the case of an earthquake, he would cite an instance that occurred in Valparaiso in 1851. A family party were sitting in a room after dinner, and on the table was one of the old-fashioned oil lamps, with a large globe and a chimney-glass within it. An earthquake took place, the family rushed out, and on their return they found the globe on the ground; it had been thrown over the chimney-glass, which remained in its place. One could easily imagine, therefore, what the effect would be in a lighthouse, if the joint had a vertical movement. The lantern might be destroyed. From his experience of the structures erected by the Spaniards, he believed that the more solid the structures, the better they resisted earthquake shocks. In Panama there was a single-stone arch of an old Spanish church, spanning 40 or 50 feet, and it remained to the present day. On the Pacific coast, numerous bridges had been built by the Spaniards with solid stone arches, which had resisted every earthquake, not a crack being visible in them. He believed that Nature had pointed out the best course to pursue in structures of that kind. In the lighthouses described, so far as he could judge from the illustrations, there was one defect—a want of batter. Every structure that he had erected in an earthquake country had a great deal more batter than would be given to a similar structure in England. The broader the base the better. An analogy might be found in the buttress-tree, which spread out on all sides in a manner remarkably like buttresses.

Dr. Pole could testify, from correspondence he had had with Japan, how highly Mr. Brunton himself and his work were valued by the Japanese, and by his brother engineers in that country. He had placed upon the wall a Japanese map on a large scale, which had been recently sent to him by Mr. Boyle, the Chief Resident Engineer of the railways, who had marked upon it the lines executed and projected. He thought, at some future time, a Paper upon Japanese railways might be interesting to the members of the Institution. He had also placed upon the table some photographs of railway works in Japan. The country was no doubt a land of earthquakes. Near Yokohama there was a celebrated conical mountain, Fusi Yama, always seen in Japanese lacquer-work, very high, and visible at a long distance. It was a volcano, which had been in action within the historical era, but it was now extinct. The volcanic influence, however, remained, and the country, especially in that particular neighbourhood, was very subject to earthquakes. He need not say that that liability had attracted the attention of the railway authorities, who had endeavoured to make their works strong enough to withstand the shocks. A great many bridges were required, and many of them had been constructed of iron sent out from England. In their design the probable effects of earthquakes had also been considered. But there had been no shocks of importance since the railways had been opened, and experience had therefore yet to be gained.

Mr. **Abernethy**, Vice-President, observed that probably there was something special in the character of the Inland Sea, otherwise he could not agree to the principle laid down by the Author, to put no lights where the headlands were bold and well defined, or where no danger existed. In this country the most important class of lights were those placed upon salient headlands, in order that during on-shore gales vessels might have a good offing, and ascertain their proximity to land as early as possible. The system of lighthouses might be divided in three parts: 1, the lighthouse upon prominent headlands; 2, lights to define the position of harbours; and 3, guiding and leading lights to guide vessels into harbour. He could not gather from the Paper that this order had been observed. With reference to the effect of earthquakes, he was of opinion that weight and solidity, and not slightness of structure, were best adapted to meet shocks of that description. An extraordinary example was that of the great aqueduct from Cintra to Lisbon, which at one point was at least 250 feet in height, and which was within the zone of the great earthquake that destroyed nearly all the principal buildings, when this structure was uninjured and remained intact to the present day. This fact among others led him to believe that, in order to meet the shock of earthquakes, solidity and weight were essential elements.

Mr. **Woods** said he had been engaged in the construction of buildings for Peru, where earthquakes were very prevalent, and he had always understood, from the information he had received, that buildings of slight construction, whether of wood or of iron framing, were better adapted to resist earthquake shocks than more solid erections. He could mention cases in which light structures had stood very severe earthquake shocks. For instance, at Pisco, a small town on the coast of Peru, exposed to the action of the sea with heavy surf, there had been built from his designs, about twenty-five years ago, a light wrought-iron pier, with screw piles, extending 2,400 feet out to sea. Six or seven years ago a great earthquake occurred, by which the city of Arica was overwhelmed. A wave of the sea rushed into the town, carrying with it a gun-brig ½ mile inshore, where she now lay high and dry. The pier sustained the shock of the earthquake. The motion of the platform was so severe, that persons could not stand steadily upon it, but the pier suffered no injury whatever, the undulations passing through it without affecting its stability in any way. He believed the pier was now as sound as when it was first erected. He might mention another instance, that of a building erected at Payta, also on the coast of Peru. It had a light iron framework, lined with wood, and it had been in existence twenty-five or thirty years, after sustaining every shock that had occurred in that part of the country. He did not know whether there had been sufficient experience to test the effects of earthquakes on the solid lighthouses in Japan, but he was inclined to think that a severe shock might occasion them considerable disturbance. With regard to the proposal to fit the lighthouse with lantern tables, he thought an elastic fixing would be as serviceable as the method described in the Paper. If the platform to receive the lanterns were secured to a proper table, by means of intervening springs, he believed all the effect supposed to be obtained by a ball and socket joint would be obtained.

Mr. **Beaumont** said with reference to the partial revolution of one portion of a building upon another, it had been shown by Mallet, in his various works on the phenomena of earthquakes, that it was due to the difference between the frictional adhesion of one part of the building and that of the other, the inertia of the building allowing that part that was not as well fastened as the other to remain nearly still while the other part or parts moved backwards or forwards in the first or second phase of the shock.[1] In the case of lighthouse structures, where the different courses were properly dovetailed one into another, of course that would not take place; neither would structures built of iron be subject to any such movements.

Mr. **Brunton**, in reply, said one reason for the large proportion of fixed lights was their greater simplicity, a matter of importance in a country like Japan; but it should be understood that only part of the scheme for the illumination of the coast had at present been carried out; in order to introduce the necessary distinctions, the lights still to be established would be chiefly revolving. The natives would by that time have gained experience, and might be intrusted with a revolving machine; but, at the commencement of the undertaking, the importance of having a simple apparatus could not be exaggerated.

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[1] *Vide* Transactions of the Royal Irish Academy, vol. xxi., p. 51; and Reports of the British Association for the Advancement of Science, 1847–1858, *passim*.

Doty's burner was adopted in Japan in 1872, on account of the difficulty experienced in procuring suitable vegetable oils, and because at the time no other suitable mineral oil burner was available. Subsequent improvements in burners by Mr. Douglass tended to show that good colza oil could be consumed to give equally as good results, photometrically, as mineral oil; but this was not universally admitted. The standard power of each size of flame, fixed for the purpose of testing the oils used in Japan, and the standard consumption to attain these powers, were as follows:—

	Power.	Rate of Consumption of 1 Gallon.
4-wick colza oil lamp	= 255 candles,	4¾ hours.
4-wick mineral „	= 270 „	5 „
3-wick colza „	= 150 „	9 „
3-wick mineral „	= 190 „	9¼ „
2-wick colza „	= 50 „	17 „
2-wick mineral „	= 75 „	17½ „
1-wick colza „	= 10 „	86½ „
1-wick mineral „	= 19 „	92 „

Flames of these strengths were invariably maintained in the Japan lighthouses. These figures were the result of repeated, independent experiments. Allowing that only 23 per cent. more heat was evolved by mineral oil, yet the accumulation of that extra heat in a lantern during a calm tropical night was, in his opinion, sufficient to produce the effects he had stated.

The Japan Lights had been thus classified in the Paper:—1. Lights required by the treaty powers, which were principally ocean lights; 2. Lights for the Inland Sea; 3. Local lights, these being mostly harbour lights; 4. Ocean lights established by the Government. These, in his opinion, included the three divisions named by Mr. Abernethy. He had not advocated as a general principle "to put no light where the headlands were bold and well defined, or where no danger existed;"[1] but it was one which had been adopted, after many consultations with nautical men, in reference solely to the lighting of the Inland Sea, where the circumstances were peculiar.

The Paper was necessarily of a general character, because it described a system of lighthouses and not any one in particular; but as many details of construction had been given as were deemed to be of interest. He had consulted all available authorities regarding the nature of the structures best calculated to resist earthquakes; and there seemed to be a general approval of solidity, weight, and strength, as opposed to lightness and flexibility. He accordingly adopted that principle. A lighthouse was a simple erection, and he had given in the Paper the form of each, the thickness of the walls, the sizes of the stones, and the manner in which they were arranged. The batter of the walls was in every case considerably greater than would have been thought necessary in this country.

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[1] *Ante*, p. 4.

Many violent earthquakes had occurred since the lighthouses had been erected. But, on account of the inconveniences occasioned by the unsteadiness of the upper part of the aseismatic arrangement, as designed by Messrs. Stevenson, it was found necessary to secure it, and so prevent its acting. From a desire to give the design as full a trial as possible, he had repeatedly given instructions to lightkeepers at different stations to keep the tables free to act, and to report to him the result. In every instance their reports showed that the movements caused by the operation of trimming the lamps, or of performing the various other duties connected with the light—and in an apparatus having twenty-eight separate burners these were frequent—seriously deranged the flames, and prevented the machinery in revolving lights working smoothly. Under these circumstances, it became, in his opinion, imperative to prevent the tables acting. The opinion of the Messrs. Stevenson, that the tables might easily be made less sensitive without rendering them incapable of motion, was precisely the problem still to be worked out. The degree of sensitiveness to be attained was one which, while unaffected by ordinary disturbances, would afford a free motion in earthquakes. Probably to attain this might present some difficulty. An earthquake had recently displaced the glass cylinders of the twenty-one reflector lamps at Tsurugisaki lighthouse. These merely stood on their bases, and were not supported in any way. This was the only damage done at the time in the lighthouse. The earthquake, though apparently not so severe as some previously experienced, had a peculiar motion. It turned the upper six or seven courses of the stonework of one of the chimneys of the keeper's house—a column of ashlar masonry about 2 feet by 3 feet, and 10 feet high—half round, and left it in a diagonal position to the lower part, without other fracture or displacement. Mr. Mallet, in his "History of the

Neapolitan Earthquake of 1857," and Mr. Lloyd, both mentioned that they had observed similar twisting movements. In close proximity to Tsurugisaki there were three dioptrical lights, viz., Noshima, Kannonsaki, and Jôkashima, where the earthquake had been as severely felt. In these, the large glass cylinders for the single flames were secured both at the top and at the bottom, but no derangement whatever had occurred. So far as the experience —which was not very extensive, however, in Japan—went, dioptric apparatus was as little liable to derangement from earthquakes as catoptric. Mr. David Stevenson, in his Paper read before the Royal Scottish Society of Arts, said that any sudden lateral motion of the earth on which a building rests, must be transmitted through the rigid and unyielding material of the structure to the summit, where the violence of the shock would be aggravated. Having regard to the vibratory character of the movement in an earthquake, the motion being as much backward as forward; and also to the fact that no building material was absolutely rigid, or unyielding, it was clear that a shock would gradually lose in intensity as it left the foundation and approached the summit of a structure. As a matter of fact, earthquakes, which had been sufficiently severe to frighten the lightkeepers and their families out of their dwellings, had not been felt at the summits of the higher lighthouse towers in Japan. This was of great importance in the construction of buildings in earthquake countries. Recent destructive earthquakes in Japan had invariably indicated a vertical motion only; and the destruction to erections had occurred on the sharp downward movement which always followed the upheaval. Messrs. Stevenson's aseismatic tables did not provide for such a movement.

The Author begged to acknowledge the facilities which were afforded him by the Messrs. Stevenson, before he proceeded to Japan, for obtaining a detailed and accurate knowledge of lighthouse construction. The records of their office were placed at his disposal, and they personally assisted him in every way, especially as regarded the design and construction of the optical apparatus, in which matters they were pre-eminent. He also mentioned the assistance he had received at one time from H.E. Mr. Wooyeno, Minister in England for Japan, who, almost at the outset, was the commissioner appointed by the Government to take charge of the work. By his energy and high intelligence he succeeded in extricating the work from serious difficulties in which it was involved, owing to the peculiarities of the native workmen. Unfortunately his Excellency only remained in the Lighthouse Department for a short time, by which the assistance of a willing and an able colleague was lost, just at the time when such services were most needed.

Mr. W. D. CAY referred, through the Secretary, to the advantages of the use of gas for lighthouses in situations occasionally inaccessible. He had recently completed the works for lighting, in this manner, the lighthouse at the seaward extremity of the New South Breakwater at Aberdeen, the tower of which had been already described at the Institution.[1] The lightkeeper was unable to pass along that breakwater during storms on account of the waves, so that it was necessary to have a constant light; and it had been so arranged that this was kept low during the day, and the full pressure was turned on at sunset by a cock placed on the shore. The gas was brought from the town of Aberdeen in a 2-inch pipe, upwards of 2½ miles long, crossing the river Dee by the Suspension Bridge in a lead pipe, and was carried along the breakwater in a wrought-iron pipe sunk in a groove cut in the concrete, and covered with a pitch-pine beam. A gasholder, inclosed in a house, was provided at the shore end of the breakwater, holding a week's supply of gas; and a dry gas-meter, placed on the pipe from the town, prevented the return of gas towards the town, when through any cause the pressure in the supply pipe should be less than the pressure in the holder. These arrangements had been completed, and tested, and had been found to work in a satisfactory manner. The total cost, including the lighthouse which had been built of concrete in 1873, the light-room, lanterns, gas supply works, &c., would be about £2,200.

Mr. J. J. COLEMAN remarked, through the Secretary, that it was only within the last few years that mineral oil had been used for lighthouse purposes. Previous to 1868 the possibility of using mineral oil in lighthouses had been considered by the Trinity House, but the then existing lamps were not found suitable for its application. In the month of March of that year Captain Doty submitted to the Trinity House authorities a burner with a concentric wick, which he asserted would answer the purpose. This, however, was a crude affair; and the Deputy Master lent Captain Doty a lamp of the first order as a model. Another and more perfect burner was constructed, and sent in the course of the same year to the Trinity House. Professor Tyndall examined it, and did not advise its adoption; but, during the two ensuing years, experiments were made by Mr. J. N. Douglass, M. Inst. C.E., who altered the existing Trinity House burners, so as to adapt them for burning mineral oils. A first order light so altered was used successfully at Flamborough Head in 1871.[1] In the meantime, Captain Doty had succeeded in introducing his burner, and the use of mineral oil for lighthouse purposes, into France; the late Emperor of the French taking considerable interest in the subject. He was also successful in interesting the Commissioners of Northern Lighthouses, through their Engineers, Messrs. D. and T. Stevenson. Dr. Stevenson Macadam examined the photogenic power of mineral oil when burnt in Captain Doty's lamp, and made an exhaustive report to these gentleman on the 31st of December, 1870. Assuming a given weight of colza oil to yield a light denoted by 1,000, Dr. Macadam stated that an equal weight of mineral oil furnished in

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 123.

First order	of lamp,	a light	equivalent to	1,184
Second	„	„	„	„ 1,544
Third	„	„	„	„ 1,734
Fourth	„	„	„	„ 2,040

and concluded thus:—"I am of opinion that paraffin oil, consumed in Doty's lamps, alike from readiness in trimming and lighting up, from steadiness of flame, and from high photogenic power, possesses decided advantages over colza oil for lighthouse illumination."[2] In April of the same year, Dr. Macadam reported that he had got still more favourable results with the first and second order of lamps, by an alteration of the wicks. These experiments were simultaneous with practical trials of the oil at Girdleness, Pladda, and Pentland Skerries lighthouses. In December 1871 appeared a report by Professor Tyndall,[3] who had been employed by the Trinity House to examine into the relative merits of the lamp used by the Trinity House and that introduced by Captain Doty. Dr. Tyndall's experiments lasted fifteen days, and he thus concluded an elaborate report on the matter:—"With oil No. 1, which appears to be more suitable for lighthouse purposes than any other, the Doty lamp shows a small but distinct superiority. As regards this oil, the simple changes introduced by Mr. Douglass into the Trinity burner appear to be almost as effective as the more elaborate devices of a central button and an external jacket introduced by Captain Doty. But as regards the combustion of oils richer in carbon, and, therefore, more liable to produce a smoky flame, the Doty lamp possesses, within certain limits, a distinct advantage. On the whole, therefore, I should pronounce the Doty lamp the more effective of the two." Mr. Douglass' alterations of the old colza burner were as follows, according to Dr. Tyndall :—Altering the tips of the wick cases, introducing a perforated disc at the centre of the flame, and modifying the form of the glass chimney, also altering the level of the oil (an expedient previously adopted by Captain Doty). The issue of this report was followed by a voluminous correspondence, extending from 1871 to 1874, between the Trinity House, the Board of Trade, the Northern Commissioners, Messrs. D. and T. Stevenson, and Captain Doty, relating to certain claims on patent rights and proposals to settle the same.[1] In reference to this report, the question of vegetable oils *versus* mineral oil was considered by Dr. Tyndall to have been settled by previous reports of Dr. Macadam, Mr. Valentine, of the Royal College of Chemistry, Mr. Douglass, and Messrs. D. and T. Stevenson. After quoting the report of Mr. Douglass to the Trinity House, that with mineral oil used in a single-wick lamp an economy of 72·7 per cent., and with a four-wick burner of 60·5 per cent., had been gained, as against the results obtained by the use of colza oil, Dr. Tyndall remarked :—" This consensus of evidence leaves no doubt upon the mind that, as regards cost and illuminating power, the paraffin light really possesses the advantages claimed for it." Meanwhile, the French Government had been actively at work, and by the year 1872 sixty-nine lighthouse stations in France were being supplied with paraffin oil. In 1873 M. Reynaud reported to the Foreign Office[2] that Captain Doty had been awarded 10,000 francs by the French Government in recognition of his services; and in the same year the Duc de Broglie reported, through Lord Lyons,[3] that two kinds of burners were giving good results, viz., the Doty and a modified form of Fresnel lamp, made by M. Henry Lepaute; and that they cost the administration the same price, viz. :—

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[1] *Vide* P. P. Correspondence relative to the substitution of mineral oils for colza oil in lighthouses, p. 7, 6 February, 1872.

[2] *Vide ibid.*, pp. 13 *et seq.*, 28 June, 1871.

[3] *Vide ibid.*, p. 23, 6 February, 1872.

	Francs.
Five meshes	60
Four „	50
Three „	40
Two „	32

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[1] *Vide* P. P. Correspondence relative to the substitution of mineral oils for colza oil in lighthouses, *passim*, 27 June, 1872; 6 February and 1 August, 1873, and 22 May, 1874.

[2] *Vide ibid.*, p. 30, 1 August, 1873.

Vide ibid., p. 1, 22 May, 1874.

In 1874 the Trinity House reported to the Board of Trade that paraffin oil was used in nineteen English lighthouses, and they recommended its introduction into twenty more, and a contract was entered into with Messrs. De Mille and Co. for burners, the prices being as follows[1] :—

	£.	s.
Five wicks	10	15
Four „	8	0
Three „	6	0
Two „	4	10

In the same year, also, the Board of Trade sanctioned the Northern Commissioners introducing (through Messrs. D. and T. Stevenson) the Doty burner and mineral oil into all Scotch lighthouses. As regarded the economy of mineral oil for lighthouse purposes, its cost had always been under that of colza, or other fatty oils; frequently only one-quarter, and never more than one-half the price. In foreign stations, it would appear from the Paper that it was also economical, notwithstanding the expense of packages and freight. Mr. Brunton had remarked correctly, that much care was required in the selection of the oil, and in freeing it from the volatile constituents which were always present in crude or imperfectly refined mineral oils. If a standard of 145° to 150° flash point were too low, it would be easy to manufacture an oil having a flash point even as high as 250°, which was the quality of oil supplied for the use of saloon lamps of marine steamers. There was one point which the Author seemed to think of importance, viz., the heat produced during the combustion of mineral oil, as compared with that evolved during the combustion of vegetable oils. To use the words of the late Professor Rankine: "The total heat of combustion of any compound of carbon and hydrogen is the same as the quantities of heat which the hydrogen and carbon contained in it would produce separately by their combination with oxygen, and when hydrogen and oxygen exist in the compound in proper proportion to form water, these constituents have no effect on the total heat of combustion."

The average constitution of vegetable oils was:

Carbon	76
Hydrogen	12
Oxygen	12
	100

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[1] *Vide* P. P. Correspondence relative to the substitution of mineral oils for colza oil in lighthouses, p. 17.

Applying the above rules, the available carbon and hydrogen for producing heat in say 100 lbs. of the oil would be:

	lbs.
Carbon	76
Hydrogen	10½

Again, the average composition of mineral oils was:

	lbs.
Carbon	85
Hydrogen.	15
	100

Now the number of British heat units produced by burning 1 lb. of hydrogen was 62,032, and by burning 1 lb. of carbon 14,500, therefore the following calculation would show the total heat of combustion of vegetable *versus* mineral oils:—

Vegetable oils	Carbon	76	× 14,500 =	1,102,000
	Hydrogen . . .	10½	× 62,032 =	651,336
				1,753,336
Mineral oils	Carbon	85	× 14,500 =	1,232,500
	Hydrogen . . .	15	× 62,032 =	930,480
				2,162,980

Thus mineral oils evolved 23 per cent. more heat in burning than vegetable oils; but, on the other hand, taking into consideration the increased light they gave, the amount of heat evolved per unit of light was actually less with mineral oils than with vegetable oils, when the average results of various burners were taken as the basis of calculation. It appeared probable that the breakage of glass chimneys, observed by the Author, was owing to the fact that a mineral oil flame was generally more concentrated than that of a vegetable oil, thus localising the heat produced. He would suggest that if this difficulty caused too much trouble, the form of the chimney, or the construction of the burner, should be altered so as more effectually to spread the flame.

GEOLOGY OF JAPAN.

At this meeting the PRESIDENT directed attention to an interesting series of 123 specimens of the Mineral Products of Japan,—a gift to the Institution from the Government of that Empire; whereupon it was

Resolved unanimously,—That the best thanks of the Institution* be recorded, and be tendered to the Japanese authorities, for the interesting and valuable Collection of Geological and Mineralogical Specimens which they had offered for the acceptance of the Society.

In speaking to this Resolution, Dr. POLE desired, as one of the English engineers whom the Japanese Government had honoured with their confidence, to remark upon the interest taken by the authorities in engineering works, and how actively those works were being introduced. It was a pledge of the earnestness with which this was being done, that the authorities were investigating very carefully the mineral resources of the country, as was abundantly proved by this admirable collection of specimens. A great deal of information had been acquired, which was not formerly possessed, showing that the country was exceedingly rich in mineral products. The Government had not confined their attention to small specimens for exhibition merely; for he had, within the last few days, received samples of limestone from Japan, which he had been commissioned to get analysed, with a view to ascertain whether hydraulic lime could not be obtained, so as to save the large expense involved in the importation of Portland cement from England. The specimens presented to the Institution would no doubt prove extremely valuable. Considering the connection of English engineers with Japan, which he hoped would long continue, it would be interesting and useful to know what the products of the country were, which could not be better shown than by the specimens presented. But there was another reason for feeling grateful to the Japanese authorities—the kindness shown by them to the large staff of English engineers in that country. Many members of the Institution, and other Englishmen and Europeans, were engaged there, and all gave but one account of the behaviour of the Government to them. Formerly their lives would have been in danger, but now they were perfectly safe, and were treated with the greatest courtesy and consideration.

His Excellency Mr. WOOYENO, the Japanese Minister, expressed, through Mr. Nagasaki, his great gratification at the statement that the collection of minerals sent by his Government was valued by the Institution. He should always be glad to do anything in his power to promote the interests of so large and important a body, and to advance scientific knowledge.

November 21, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,453.—"The Fracture of Railway Tires." By WILLIAM WORBY BEAUMONT, Assoc. Inst. C.E.

THE durability of the tires on the wheels of railway rolling stock is one of the most important questions for consideration, as owing to their failure many fatal accidents have occurred, only exceeded in number by those arising from collisions. Thus, in Great Britain, in 1874, the fracture of tires amounted to 55, occasioning the death of 37 passengers and an enormous pecuniary loss to the railway companies. In the twenty-seven years, 1847 to 1874 inclusive, 80 tire accidents were reported upon by the Board of Trade officials, which resulted in the loss of 74 lives and in 236 cases of more or less serious personal injury. Previous to 1872 the companies made no return of accidents from the fracture of tires; in that year the number of such accidents was 58, in 1873 it was 30, and in 1874, as before stated, 55. During these three years, however, only those failures which were attended by serious results were reported; but in 1875 every one was systematically recorded. The General Report of Captain Tyler for that year comprises no less than 684 tire failures; and though these resulted in no loss of life, they caused the derailment of several trains. The absence of fatal results is probably due to the great care now exercised in the examination of tires, most of the failures having been discovered at stations.

Various explanations of the cause of these fractures have been brought forward, with various degrees of apparent support from experience. Sometimes the cause has been clearly traceable to a defective weld or to obviously inferior material, at other times to a reduction of the sectional area of the tire by rivet or screw-holes. But when not assignable to these causes, the origin of the fracture has generally been obscure, and its explanation a matter of speculation.

So far as the Author is aware, the forces productive of the fracture of the tires of wheels running over smooth and rigid surfaces have never been satisfactorily investigated. His present object is to point out what seems to be an efficient cause in the production of those strains which must exist in the material of tires prior to their fracture.

The actual cause of fracture, where that has been unexplained at the time of the accident, does not appear to have received much subsequent consideration, and the theories advanced to account for it seem to be untenable upon examination. But it is necessary here to consider some of them, beginning with that which attributes fracture to the strain put upon a tire, by shrinking it on a wheel having a slightly greater diameter than that of the inside of the tire before it is shrunk on. It has usually been assumed that this strain would produce an extension of the tire, equal to the difference in length of the circumference of the wheel body and that of the inside of the tire, before the latter is expanded by heating, for the purpose of being shrunk on to the rim of the wheel. In this assumption, however, the wheel, upon which the tire is shrunk, is considered to be perfectly rigid and unyielding; whereas, although it may be—with reference to ordinary considerations—assumed to be rigid, it is not absolutely so, and is, in fact, not so rigid as the tire. Therefore, supposing the resistance to compression and to tension to be equal in the rim of the wheel and in the tire respectively, the tensile strain thrown upon the latter cannot be more than one-half that calculated on the above assumption, for the work of eliminating the difference between the lengths of the tire and the rim is done, not upon the tire only, but through double its length, or through that of the tire and the rim together.

If a tire were shrunk on an absolutely rigid body whose circumference was somewhat greater than that of the inside of the tire, the strain upon the latter would undoubtedly be that necessary to produce an extension of its length equal to the above difference; but if the body be compressible, however little, the necessary extension will be reduced, and the strain also. Take, for example, a wheel body with a diameter of 3 feet, and a tire to be shrunk on it with a diameter of 2·995 feet, the difference in the circumferences being 0·1875 inch, and let the tire have a sectional area $A = 10$ square inches, and the rim of the wheel an area $a = 6$ square inches. Then the increment λ in the length of the tire and the decrement λ' in that of the wheel rim necessary to eliminate the above difference $(0{\cdot}1885 = \lambda + \lambda')$ in their respective lengths will be inversely as their areas, or

$$A :: a : \lambda' :: \lambda$$

and $$\frac{\lambda + \lambda' \times A}{A + a} = \lambda' = 0\cdot1178 \text{ inch}$$

and $$\frac{\lambda + \lambda' \times a}{A + a} = \lambda = 0\cdot0707 \text{ ,,}$$

Taking a co-efficient of elasticity, C, = 27,000,000, the strain f and f' necessary to produce the above increment and decrement respectively will be

$$f = \frac{\lambda C}{l} = 16{,}906 \text{ lbs.} = 7\cdot547 \text{ tons, which} \times A = 75\cdot47 \text{ tons;}$$

and $$f' = \frac{\lambda' C}{l'} = 28{,}097 \text{ lbs.} = 12\cdot543 \text{ tons, which} \times a = 75\cdot26 \text{ tons;}$$

l and l' being the original lengths of the tire and rim, the difference in which causes the above slight difference in f and f'; but as this is eliminated, the strain on the tire and wheel rim will be practically $= \frac{75\cdot47 + 75\cdot26}{2} = 75\cdot36$ tons. Thus, if the breaking strain of the material of the tire be 25 tons per square inch, the above strain is less than one-third that necessary to produce fracture, leaving on the whole tire a marginal strength of 174·64 tons, even in the case of wheel rims of such large sectional area as that assumed. The radial component of the above circumferential strain on the tire will be that expressed by the relation between transmitted forces (by a curved surface) of tangential tension and radial compression. Lagrange's theorem,[1] is here applicable, and may be thus stated :—

Let R = radial compression due to T;
T = tangential tension;
r and r' = two radii of principal curvature;

then $$R = T\left(\frac{1}{r} + \frac{1}{r'}\right).$$

In the present application of the theorem, as the tire is circular $r = r'$, and the above equation becomes $R = \frac{2T}{r} = \frac{2 \times 75\cdot36}{18} =$ 8·37 tons radial pressure per circumferential inch. With heavy

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[1] *Vide* "Traité de mécanique analytique, sec. 2 (statique), sur l'équilibre d'une surface flexible," &c., Paris, 1853. Also "Miller's Hydrostatics," Cambridge, 1831; and "Mallet on Volcanic Energy," &c., Phil. Trans., p. 173, 1873.

engine wheels these strains would probably be slightly increased, as the rim would be less free to alter its dimensions at the junction with the spokes. But between these, alteration may take place both by change of dimension and form. The resistance, however, to decrement in the length of the rim, and to the necessary radial compression resulting therefrom, is exceeding small in all except engine wheels. This remark applies especially to those carriage and wagon wheels in which the spokes and rim are of flat bar iron bent into segmental forms, the section of the rim not being one-half that assumed. It is not, therefore, necessary to enter into further calculations on this point, as the resistance offered by such wheels to the contraction of the tire must be insignificant in comparison with the tensile strength of the latter.

No account has, however, been taken of the plasticity of the material of the tire, which, especially at high temperatures, allows of its elongation by the force of its own contraction, the residual strain being only equal to the difference between the total force of contraction and that already expended at the higher temperatures in the elongation of the tire; so that even were there a much greater original difference between the diameters of the tire and rim than has been assumed, the resulting strain would probably be little more, as plasticity increases, and the mechanical equivalent of expansion by heat decreases, rapidly, with the rise to such high temperatures as would be necessary to enlarge the diameter sufficiently to get the tire on the wheel.[1]

It would seem, therefore, that the shrinking on of these tires cannot alone result in the production of a strain sufficient to cause their fracture, unless they are of bad material or workmanship. If, however, a strain approaching the tensile resistance to fracture of the material of the tire could be thrown upon it, by the elongation demanded by the difference between the diameters of the wheel and of the tire, the latter should break upon first being put to work, instead of after long wear, as is usually the case. For if that strain were alone the cause of fracture, its intensity would be constantly reduced by the tendency working would have, to make the tire accommodate itself by further elongation. Fracture frequently takes place at several points simultaneously, but it seems difficult to conceive that a simple tensile strain should induce such a phenomenon, as a tire would be relieved of all tension by one fracture, every additional fracture demanding an equal strain for its production. Assuming, however, that the material of the tire is perfectly homogeneous, and of uniform tensile strength, and that the circumferential strain is equally distributed throughout the entire length of the tire, then it is possible to conceive, that a strain equal to the tensile strength of the tire could fracture it in several places simultaneously. But unless the above conditions rigidly obtain, absolute simultaneity of multiple fracture would be impossible, and it need hardly be said that practically such conditions never exist. Except multiple fracture take place with absolute simultaneity, it could not occur as a result of tensile strain, for the first fracture would render subsequent fracturing impossible, because it would have dissipated the strain that produced it; so that any further breakage would necessitate the reproduction of a tensile strain slightly in excess of that which produced the first fracture, and for which there is no origin.

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[1] *Vide* Mallet "On the Physical Conditions involved in the Construction of Artillery," &c., pp. 40 and 152.

By far the larger number of broken tires have been fractured in several places, and of the 80 cases reported upon by the officers of the Board of Trade up to the end of 1874,

9	were fractured at	3 places,
8	„ „	4 „
5	„ „	5 „
5	„ „	6 „
2	„ „	7 „ and
6	„ „	in "several places;"

while out of 14 cases reported by the Great Western Railway Company between 1868 and 1873,

3	were fractured at	3 places,
2	„ „	4 „
2	„ „	5 „
1	„ „	7 „
1	„ „	12 or 14 places,
1	„ „	several places.

Many of those reported in 1875 also broke in several places. This large number of multiple fractures affords strong evidence of the existence of enormous internal molecular strains in the material of the tire, for it seems impossible to conclude, that a tensile strain, or inferiority of material or workmanship, even when aided by impact strain, should be disclosed by such results.

Fracture has as frequently been assigned to the reduction of the sectional area of the tire, by the holes made to receive the rivets, bolts, or screws, by which the tire is fastened to the rim of the wheel. Any such reduction of sectional area undoubtedly lessens the tensile strength of a tire. But unless these holes diminish that strength, by a proportion far greater than that borne by the reduced to the full section, it seems impossible to attribute fracture to this cause alone. In many of the forms of fastening by screws, this reduction in section is very small, for the screw-hole only enters the tire a short distance, and that, in some instances, just under the flange, where the tire is strongest. Even allowing, however, that such holes sufficiently lessened the strength of the tire to cause fracture at these points, it would not explain fracture at several points, nor fracture between two such planes of weakness. Many tires have broken in places where no such planes of weakness existed, the tire being fixed by clips, or by annular clip rings. Again, referring to the reports already quoted, it will be found that out of the 80 accidents in 1874, twenty-three tires were fractured through the solid material, and not through either a weld, or a bolt or screw-hole, although all these existed. Seventeen tires were weldless, and seven were fixed by clips or clip rings, without bolt or screw. Of these, one was fractured in five and one in six places; while the fourteen fractured tires reported by the Great Western Company between May 1868 and May 1873 were all affixed by Gibson's fastening. Of the tires that failed in 1875, four hundred and seventy-seven were fastened by bolts or rivets, but of this number only 19½ per cent. broke at the bolt or rivet-holes. These facts prove that the force which initiated fracture was not one of simple tension aided by impact, and that fracture was not due to reduction of sectional area of the tires by the bolt-holes. Further explanation of the nature of the forces productive of the fracture of a tire of good material must therefore be sought.

The alleged reduction of the strength of iron by, as well as the contraction due to, low temperature, has usually been called in to explain the fracture of tires during a frost. The effect of extreme cold upon the tensile strength of iron has not yet been definitely ascertained, though the experiments of Fairbairn[1] tend to the conclusion that the tensile strength of iron, not already 'cold short,' in ordinary frosts in this country, is not materially reduced, a conclusion supported by experience in Russia and Canada, where the cold is far greater and more protracted than in England. The moderate speed of trains observed abroad, compared with that adopted in England, undoubtedly tends to reduce the number of breakages, and the severity of the accidents attending them; but against this may be set, the superiority of English permanent way, and its better maintenance. If the difference in the strength of iron in summer and in winter were considerable, and sufficient in itself to cause fracture of a railway tire, it would be unsafe to travel in any common carriage over many of the ill-laid granite pavements during severe frost, except at low speed. None of the axles would withstand the severity of the shocks delivered through the wheels, at a velocity due to the recoil of a loaded spring, as they pass rapidly from summit to hollow of every inequality of the roadway. Again, so general a cause as frost should be evidenced by corresponding effect, and if productive of fracture of railway tires, it should be manifest by more frequent fracture, and not by isolated instances. Although there seems to be little proof, that the strength of iron to resist static strains is reduced by a low temperature, there is evidence that its power of resistance to impact is somewhat diminished by such a condition, although probably only by a fraction of the extent often assigned to it. If this reduction in strength were sufficient to cause the fracture of one tire in a train, all the rest of the tires of the same train, running under the same conditions of temperature, should be fractured, unless that one tire was of originally bad material, or was weakened by a defective weld or by a bolt-hole. But such has not always been the case, many tires having broken through solid and good material, and not at a weld or bolt-hole, although both have existed in the tire. Again, if low temperature alone could initiate fracture, the lowest temperatures should be most fruitful of such results; so that the intense cold of some countries would be accompanied by such numerous tire and axle breakages, as to make railway travelling almost impossible, except at very low speeds.

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[1] *Vide* Report of the Seventh Meeting of the British Association for the Advancement of Science, vol. vi., p. 377; and "On the Application of Cast and Wrought Iron to Building Purposes," p. 63.

Although there is no evidence to show that the occurrence of a moderate frost can by itself reduce the resistance of iron to impact strains, so as to make a tire unable to withstand the shocks brought to bear upon it, there is sufficient proof that frost, in conjunction with other causes, exerts some influence in bringing about a fracture which without it would have been delayed.

Of the 94 accidents before referred to, 17 per cent. happened in the spring, 14 per cent. in the summer, 9 per cent. in the autumn, and 59 per cent. in the winter; thus the number of fractures during the three hottest months has been only 23 per cent. of the number in the three coldest months. But these figures do not correctly represent the comparative strength of iron under different temperatures; for the hardness of the ground during frost, by diminishing the resilience of the way, and thus converting it into an anvil, may well account for the excess of fractures in the winter, resulting from the severity of the impact strains which the tires have at such times to bear. As a result, however, of the much wider range of observation and systematic record in 1875, the relation given by the above figures is reversed; for in that year fifty tires failed in January, thirty-one in February, thirty-eight in March, seventy in April, seventy in May, sixty-seven in June, sixty in July, fifty-nine in August, fifty-seven in September, fifty-seven in October, sixty-four in November, and sixty-one in December; the greatest numbers being in April and May, and the smallest in January and February.

Of 61 steel tires which broke on the Moscow-Nishni railway during the winter of 1871–2, the cause of fracture could only be ascertained in 18 cases, the fractured surfaces being rusted; but 8 of these were attributed to inferior metal, 7 to excessive strain in putting on the tires, and 3 to indifferent quality of metal combined with too great wear. Fourteen tires broke through bolt-holes, and three through screw-holes, while no breakages occurred with the tires on Mansell's wood wheels.[1] Thus the actual cause of fracture can only be considered as ascertained with certainty in about 17 of these cases, the remainder, including most of those in the 18 enumerated, being of unexplained origin. As no breakages occurred with Mansell's wood wheels, and steel tires were more affected by frost than those of iron, it seems obvious that the excess of fractures during winter is mainly due to severe impact caused by the hardness of the way.

The number of axles broken on the German railways during 1873 was 77 in the six warmer months against 68 in the six colder months; and though the winter was a mild one, the fact affords a striking proof of the uncertainty of the alleged decrease of the strength of iron during frost. Were very low temperature by itself so active a cause of the fracture of railway tires, it might have been expected that every frost would have been marked by fractures; but long periods have elapsed with comparative immunity from such accidents, followed by a shorter period marked by their excessive frequency. Thus it was found that the accidents from broken tires reported upon on the Midland railway between 1847 and 1871, a period of twenty-three years, only numbered 5, while between January 1871 and December 1874, or in four years, no less than 10 such accidents occurred on the same railway, that is, double the number in about one-sixth of the time. This proves that the cause must be of slow growth, and that the breaking strain must be so nearly approached, that an unusually severe shock or a slight reduction in strength, such as might be caused by frost, is all that is necessary to complete the conditions of fracture.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 351.

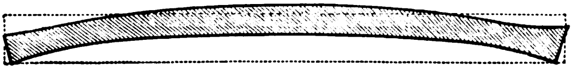
The contraction of a tire during frost has been sometimes supposed to cause its fracture, by throwing an increased tensile strain upon it; but this supposition seems without foundation, for the wheel body is subject to the same conditions of temperature, and the co-efficient of contraction of the materials of the tire and wheel cannot be materially different. Let it be assumed, however, for the sake of argument, that a wheel body, of perfectly rigid material, not subject to alteration in volume by alteration of temperature, is surrounded by a wrought-iron tire, 150 inches long and 10 square inches in section. Suppose now that the tire cools through a range of 20° Fahr., or from say 50° to 30° Fahr., and that its co-efficient of lineal contraction = 0·0000064. Its lineal decrease will then be 0·0192 inch, and the mechanical equivalent of this reduction will be 1·5 ton per square inch, or 15 tons on the whole tire, a strain quite insignificant compared with its ultimate strength, even upon the assumption of the above physically impossible conditions.

The foregoing theories have been most frequently appealed to when the cause of fracture has not been self-apparent; but the Author believes them to be inadequate to explain, first, the fracture of tires of good material and workmanship; secondly, the fracture of tires at several places; thirdly, that a railway may be free from such breakages for a long period, followed by a shorter period of frequent breakage; fourthly, the fracture of tires at several places through the solid part rather than through bolt or rivet-holes; fifthly, that tires generally have run several thousand miles before they fly to pieces.

The strain caused by shrinking on an engine tire, and that of centrifugal force at high speeds, when combined with the loss of strength and the severity of impact during frost, may together amount to a considerable portion of the total resistance of its material. As they cannot, however, be considered sufficient to explain fracture in many cases, the Author will proceed to describe what seems to be the cause of those strains which must exist in a tire at the moment of its fracture; and for this purpose will refer to some well-known facts which, so far as he is aware, have never yet been appealed to.

If a flat stout bar or piece of plate of cast or wrought iron, or other metal, be subjected on one of its surfaces to long-continued light hammering or rolling when cold, that surface will become compressed or elongated to an extent dependent upon the duration and intensity of the hammering or rolling. If the plate or bar be thin the effect of compression by hammering will extend throughout its thickness, and little change will result except of tension in orthogonal directions in the plane of the surface; but if the plate or bar be thick, relatively to one or both of its other dimensions and to the force producing compression at any moment upon one surface only, the effect will be that that surface will be compressed and elongated in all directions, while the opposite surface will remain unchanged. The effect of thus altering the relative dimensions of the two surfaces, of the originally flat plate or bar, will be to make it assume the form of an umbo, or of a bow with the convexity towards the rolled or hammered surface. The amount of this convexity depends upon conditions attending the rolling or hammering, as well as upon the duration and intensity of these. Examples of this elongation of one surface of a plate or bar, and its attendant results of convexity of that surface, are not infrequent. A familiar example of its practical application in the foundry, is that of straightening cast-iron plates, such as coping plates which have become bent in cooling, by placing the convex side upon an anvil, and lightly hammering the concave side. Tramway plates, under the rolling action of the wheels of heavily-laden vehicles, afford another example. These, if of sufficient thickness to give the desired protection to a roadway, become converted into shallow inverted dishes. Fig. 1 is a section of a tram-plate put down on Westminster Bridge in 1861, and taken up in 1873, after twelve years' wear. It affords an example of the intensity of the differential strains thrown upon the material of the plate by which the curvature has been effected, because a

FIG. 1.



Section of a tram-plate from Westminster Bridge taken up in 1873. The dotted lines represent the original form and thickness of the plate as put down in 1861.

large portion of the surface has been worn away, chiefly by the aid of the sand and dirt with which the plates are always covered. This grinding away of the surface of the plate contemporaneously with its compression almost wholly prevents the accumulation of the bending force, for the compressed material which would exert that force is nearly all removed; so that the fact of the production of the curvature of these plates, under such conditions, is a strong proof of the forces brought into play by the rolling action of the wheels of loaded vehicles. Although it took twelve years to produce the curvature shown by the section, a less number of years would, under more favourable conditions, suffice to bring about the same result.

At the time of the Crimean war, a portion of Woolwich Arsenal, traversed by heavily-laden vehicles, was covered with cast-iron plates, for the purpose of protecting the roadways and reducing the draught resistance upon them. After these plates had been down a few months, they assumed the form of inverted shallow dishes, and it was in consequence necessary to take them up. In each of these examples the plate was vertically free, and the force exerted by the extended upper surface was expended in the production of the curvature described. But if the bending thus originated had been opposed by a competent resistance, the internal molecular strains engendered by the extension of one surface would gradually have become sufficient to cause rupture, either by the crushing of the upper portion of the plate, or by the tearing asunder of the lower portion, just as an arched rib, loaded with a breaking weight, and supported only at its lower extremities, would give way by crushing or crumpling at the upper, or by tearing asunder at the lower edges or flanges. Many more illustrations might be adduced, but it is unnecessary to dwell upon them. It now remains to correlate these facts, and to draw such conclusions as they warrant, in explanation of the conditions involved in the often apparently anomalous fracture of railway tires.

From what has been said, it will not be difficult to see that the rolling and hammering action, to which railway tires are subjected, must so extend and compress some parts of their outer surface, as to create those internal molecular strains, the result of which is illustrated in a small degree by Fig. 1. From the time a tire is put to work, and begins to roll under its load along the hard road of iron or steel, it is subjected to a "rolling out" of the surface, at a rate depending principally upon the load, the velocity at which it is impelled, the elasticity of the wheel and the permanent way, and the nature of the material of which the tire and the rails are composed. If the pressure upon a unit of surface of the tire were only such as to bring into play the elasticity of the material, no extension or permanent compression would take place; but as the pressure upon the small surface, at any moment in contact with the rail, is vastly greater than that necessary to surpass the elastic resistance of the material, it loses ductility, and permanent compression and elongation of the surface are the result.

Every revolution of the wheel is attended by a fresh permanent loss of ductility of the material of the tire; for although repeated application of a similar weight or pressure may not reduce its elastic resistance, the ductility will be drawn upon by every fresh application of the pressure, until all ductile resistance is lost, and rupture approached. Thus film after film of the tread of the tire is permanently compressed and elongated, until the thickness so molecularly altered becomes sufficient to create internal differential strains upon the tire, of such magnitude as to surpass its resistance to rupture, or so nearly to approach it, that an unusually heavy impulse, or other extraneous force, is alone necessary to effect such a result. Considering the small surface of tire at any moment in contact with the rail, and that the load upon this small surface per unit is very great; that the velocity with which the wheel is impelled is often 90 feet per second; and that the speed with which a tire strikes any projection, or descends from one level to another, as at a defective fish-joint, is that due to the recoil of a heavily loaded spring, probably approaching 1,000 feet per second, —it is not difficult to see that the compression of the tread of a tire under such conditions may be very rapid, and a run of a few thousand miles sufficient to create strains productive of fracture. Thus, when the outer and lengthened portion of a wheel tire is under compression, and the inner portion correspondingly under tension, at some period this compression and tension will end in a tendency to tear asunder the inner portion, or to crush or crumple up the outer portion. Or,—as would seem to be more generally the case,—these antagonistic forces, in equilibrium while the wheel is running smoothly, will insure the ruin of the tire as soon as that equilibrium is destroyed, by a blow such as is sure to be met with while running at high speeds with heavy loads.

Confining attention for the moment to a tire without weld, and without screw or bolt-holes, it may be assumed that the differential forces are diffused equally throughout the whole length. When, therefore, these forces are nearly equal to the total resistance of the tire to rupture, being elastic forces, they will, on an abnormal shock being delivered upon the tire, cause it to burst, because the forces tending to rupture at every point in its length are thus made to exceed those resisting them, in a time measured by the transit velocity of wave-impulse through a homogeneous material. This is probably not less than 1,500 feet per second, so that the shock may be considered as practically simultaneous throughout the length of the tire. The forces, therefore, which previous to the shock were supposed to be equilibrated by their resistances, being internal, tend, when that equilibrium is destroyed, to produce fracture at every point in the tire. A flat tram-plate which has its upper surface compressed and elongated, being vertically free, can accommodate itself by an upward convexity to the condition of differential surface dimensions; but the circular form of a railway tire prevents any such accommodation by bending. Instead, therefore, of the differential strains being expended in producing change of form, the tire is, in any assumed segment, in a condition analogous to that of a bent girder loaded on the convex side by a force which, when aided by a slight shock or other extraneous addition, becomes sufficient to overcome its resistance to rupture.[1] It will, however, be seen that it is not a necessary condition that every one of several fractures in a tire should take place with absolute simultaneity, because the precedence of one fracture will render those internal forces which produced it free to initiate fracture in as many places as may be necessary to satisfy or expend the internal differential strains. These strains may, when one fracture has taken place, be dissipated by the bending of the tire.

But besides explaining the conditions of fracture of a tire not weakened either by a weld or by bolt or screw-holes, it is necessary to consider the fracture of tires weakened by these —not indeed to find the explanation of fracture at such points of weakness, for that may perhaps be considered as sufficiently obvious, but to find the reason of fracture when that takes place through the solid material of the tire, and not through screw or rivet-holes.

In the accident at Shipton, in December 1874, the tire was affixed to the body of the wheel by four rivets. The tire broke at two places, each about midway between two rivet-holes, through the solid material, which was iron, though one fracture was surmised to be at a weld. This is only one of many cases of fracture through the full section rather than through the reduced section at a rivet or bolt-hole. The explanation is not difficult. At a rivet or bolt-hole, the continuity of the tire is broken; and as these holes are usually near the centre of the tread of the tire, the continuity is broken just at the part subject to the greatest compression. The result of this is that round these holes the tangential and transverse compression, produced by the impeded elongation of the material, is dissipated in an upward flow of the particles, tending to the production of a crater-like ridge, somewhat less in internal diameter than the bolt or rivet-head. This ridge is never actually produced, but is worn off either by the ordinary running, or by the break-blocks, as fast as it tends to rise above the normal surface of the tire, which at these points is relieved of almost all strain. Hence a tire, considered in reference to the forces suggested as productive of fracture, may, after it has been some time in work, be stronger at a rivet or bolt-hole, particularly as against impulse, than at a point in the solid material at some distance from it. The above may be thus illustrated:—If one end of a piece of iron of small section be subjected to repeated blows from a hammer, the result is, as in making a rivet-head, the hammered particles flow outward in all directions from the centre. But if, instead of the piece of small section, the same amount of hammering be done upon the centre of one surface of a piece of thick flat plate, the work will be consumed in compressing or elongating a portion of that surface, tending to make the plate assume an arched form, because the hammered particles, which were free to move in forming a rivet-head, are confined by the surrounding and underlying unhammered particles in the plate.

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[1] This illustration is not, however, strictly accurate, as the strains in the girder will be greatest at the centre; but with the tire the strains will be uniform throughout any assumed segment.

The differential strains created in a tire are less simple than have been hitherto considered, for the compression and elongation is most intense toward the centre of the surface, so that the tire is subjected to a transverse strain as well as being, like the centre portions, under compression. In a flanged tire, these strains are more complex, as the flange is not compressed, but, like the interior portions of the tire, remains unaltered except by the tensile strain thrown upon it by the compressed portions of the tread. Thus the tire may be considered as consisting of three portions, rigidly connected, the central portion, under a great compressive strain, being resisted by and tending to lengthen the two others, until the tensile strain, aided by an impact force, becomes sufficient to overcome their resistance to rupture. The conditions indeed warrant the suggestion, that the fracture of a tire is of a character such as is induced by a bursting strain. As a proof of the existence of the strains here appealed to, it may be mentioned that many tires when taken off the wheels present internal transverse curvature, as shown in Fig. 2, though when the tire was new this surface was flat. This curvature has the effect of keeping many tires tight on the wheels that would otherwise become loose. Although the rolling of the tire increases its diameter at *v*, the curvature tends to diminish the diameter at *x*, *x*. Of the 684 failures in 1875, three hundred and fifty-nine tires are reported as having split "longitudinally." Of these twenty-three broke at A (Fig. 3), fifty-eight at B, fourteen at C, seventeen at E, twenty-one at G, and six at K. It will be seen that the number split at B was more than double that elsewhere, the tendency to rupture from the compression of the tread, and the condition of support being greater at that point than at any other, the static and impact strains being chiefly developed at *n*, Fig. 2, and the support being at *x*, *x*.

Fig. 2.

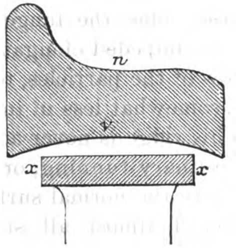
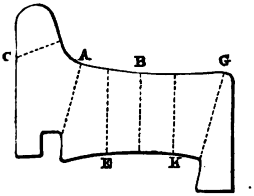


Fig. 3.



It must be pointed out that the conditions brought forward, as to the origin of fracture of a large number of railway tires, do not obtain with the tires of the wheels of ordinary vehicles. In their case, the surface in contact with a macadamised road is always much greater than with a railway tire upon a rail, and the pressure per unit of surface is therefore much less, whilst their running velocity rarely exceeds one-sixth that of a railway wheel, so that the conditions necessary for "rolling out" the surface are absent.

It would seem then that the tires upon elastic wheels have some advantage over those on non-elastic wheels, as the compression of their surface must proceed more slowly than with those upon wheels almost rigid, which act as anvils for the tires to be rolled out upon. Still it is only a matter of greater length of time for them to fail by reason of the internal differential strains.

Having now described what the Author believes to be the principal cause of the fracture of railway tires, it remains to make a few collateral remarks on the subject. If his theory be correct, however good the material and workmanship of a railway tire, it must gradually become unsafe from other reasons than simple loss of thickness; for, whether it be of steel or of iron, it is amenable to the production of internal molecular strains consequent upon the rolling out and compression of its outer portions, which must at some time become of sufficient magnitude to initiate fracture.

If steel tires or their outer portions could be hardened without sacrificing any of their resistance to rupture by impulse, their durability would unquestionably be greatly increased. The tire would then partake of the character of a hammer with a hardened steel face; the rails upon which it ran would undoubtedly suffer more from deformation of their surface than by unhardened steel or iron tires, but the life of a tire and its resistance to surface compression would, like the hardened hammer face, be increased. The durability of the American chilled cast-iron car-wheels is probably owing to the extreme hardness of their running surface, and their consequent resistance to surface compression. Unchilled cast-iron railway wheels would probably be fractured after running a few hundred miles by the forces described. These views afford an explanation of the cause of the breaking off of small patches from the tread of chilled cast-iron wheels; the detachment of which dissipates the strains induced by compression.

Although the duration of the tire in an elastic wheel is increased, yet as the tire has still to carry a load, its surface must be subject to deformation. That deformation will not proceed quite so rapidly as with a nearly rigid wheel, the inertia of which upon impact strain would have to be overcome by the tire before it was relieved by the springs of the vehicle under which it was running; whereas a good elastic wheel may be considered as having somewhat the character of a spring, and, in so far, being without such inertia. The tires of wheels fitted with breaks probably have their liability to fracture slightly diminished, especially where cast-iron break-blocks are used, as some of the compressed portions are more quickly worn off by these, and by the skidding upon the rails, than with tires not so circumstanced. From this it might be expected that the vehicles of metropolitan railways, on which stoppage at every few hundred yards necessitates the frequent application of breaks, should be peculiarly free from fractured tires; for a large number of the wheels of every train carry breaks and frequently run skidded for considerable distances upon the rails, so that the wear must be great, and is probably sufficient to dissipate the strains that would accumulate if the tires were not so worn.

The lamination of the surface of rails, particularly noticeable where the traffic is great, is an illustration of some of the effects of the rolling-out action of the wheels. The head of the rail not being wide, and the rolling being as much on one side at least, as at the centre, the portions rolled and compressed are comparatively free to flow towards the sides of the rail, where they become detached, and with rails of inferior quality lamination takes place. Tires of similar material would probably be somewhat relieved by lamination from the strains induced by rolling; but what would be gained in this respect would be more than counteracted by the loss of strength of the material.

With reference to the fastenings for railway tires it would seem, that the ultimate strength of a tire, as against ordinary wear and tear, is not reduced by the method of fastening on to the wheel by rivets or bolts. Of the 550 reported fractures in tires fastened by this means 79 per cent., or nearly four-fifths, were fractured through the full section; some of which were affixed by screws from the inside of the tire, and only penetrated partly through it. Had these been fastened by rivets or bolts passing quite through them, it is probable that the number of fractures through the solid metal would have been proportionately greater than 79 per cent. Notwithstanding this, however, the best mode of fastening is unquestionably by annular clip rings and grooves on both sides of the tire, so as to prevent the portions of a fractured tire from leaving the wheel, as it is from the latter cause that the lamentable results of some of these fractures are to be ascribed.

With a view to the prevention of the fractures of tires, the Author ventures to suggest that:—

1st. No tires should be allowed to run more than a certain number of miles, dependent upon the character of the vehicles they are running under, upon the section and material of the tires themselves, and upon the hardness of the rails. At present no sufficient information exists upon which to base an arbitrary mileage, as till recently no systematic accounts of the number of miles run by tires were kept, so that the safe mileage of various kinds of tires under the different kinds of vehicles and engines remains to be determined, by careful experiment and extended observation.

2nd. That the condition as to wear of the surface of tires should be watched with the greatest care, and when the yet to be prescribed mileage has been run, the tires should be re-turned, or, if that be not requisite, then they should be heated to a sufficiently high temperature to allow of the dissipation of the internal molecular strains, and of a rearrangement and repose of the disturbed particles. The tires might then, if not worn out, be replaced.

In conclusion, it is not pretended that the statistics in this Paper are complete, as until 1873 the railway companies did not report the accidents on their lines. The figures quoted are of those accidents reported upon by the Board of Trade officials between 1847 and 1873, with the exception of the 14 by the Great Western Railway Company between 1873 and 1874, and those reported by all the companies in 1875, many of which resulted in no accident. They do not represent all the fractures, nor the number of miles in every case run before each tire was fractured; but they do give, in a large proportion of 550 cases, the particulars and date of fracture, and the mode of fastening, and they are sufficiently illustrative for the immediate object of this Paper.

Although the Author has not been able to bring forward the results of exhaustive experiments and observations in support of the propositions he has made, it is hoped that the arguments he has adduced will lead those who have the means to consider it worth the time and trouble to carry out such experiments and observations.

The Paper is illustrated by several diagrams, from which the woodcuts, Figs. 1 to 3, have been prepared.

[Dr. PERCY

Dr. PERCY observed, through the Secretary, that it did not seem that any real investigation respecting the state of the metal of broken tires had yet been made. It would, he thought, be possible, from a thorough examination of them, to deduce decisive and important conclusions. Some years ago he published a letter in "The Times," suggesting the desirableness of preserving specimens of metallic objects connected with railway accidents; and he ventured to add that The Institution of Civil Engineers should take up the question, and be the depositary for such objects. There need be no necessity for publicly announcing the particular accidents. The Author had not mentioned Styffe's experiments on the tensile strength of iron at low temperatures.[1] His conclusion was, and he was a trustworthy and an able man, that the tensile strength increased with diminution of temperature. Mr. C. P. Sandberg had also experimented in Sweden on the subject, and concluded that, although Styffe's experiments justified his conclusion when the rupturing force was slowly applied, yet the reverse was the case when the rupturing force was sudden, as in concussive action. Dr. Percy was disposed to think that this view was correct.

Sir JOHN HAWKSHAW, Past-President, said the Author had brought forward a new subject for the consideration of those who took an interest in the question of tires. He had pointed out that the breakage of a tire might arise from the hammering of the surface; but he thought the suggestion, that a tire should not be allowed to run more than a certain number of miles, was a little premature. In order to come to such a conclusion a strict account would be required, in the record of fractures, of the number of years which each tire had run. If it could be shown that tires broke after a certain age more frequently than before that age, that might be some reason for the recommendation. As far as his experience went, no such record had been kept. With regard to the breaking of tires, there were, as in the breaking of links in a chain, an inconceivable number of causes at work, some of which would probably never be discovered. Every now and then a link in a chain would break, leading to serious consequences, though perhaps the chain might have been proved, and care taken that the iron was of proper quality; and this would happen quite as frequently to a new chain as to an old one, indeed perhaps more frequently. Old chains would often go on with fewer accidents of that kind than new ones. So it might be with tires. When he was in the habit of attending to such matters more than at present, he sometimes found tires breaking before any such process as had been described could have acted upon them so as to produce the fracture. He did not say that the process might not occasion fracture; but at all events, before the suggestion was adopted, that a tire should be allowed to run only a certain number of years, a great deal more information was required than was at present possessed.

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[1] *Vide* "Iron and Steel." By K. Styffe. Translated by C. P. Sandberg. 8vo. London, 1869.

Capt. GALTON remarked that during the last summer he had had an opportunity of seeing many wheels and tires in the United States, which had performed a remarkable amount of mileage; and the conclusion to be drawn from those observations was certainly not that the number of miles run by tires should be limited as a means of preventing accidents. It was, he believed, rather a question of material, and of the cushion upon which the tire rested. A number of Swedish wheels and axles were shown at the Centennial Exhibition at Philadelphia. One set of these was by the Swahammers Brük Foundry. It was a pair of wheels and axles of welded iron, which had run 125,000 miles (certified in the fullest manner), and they showed scarcely any wear. The tires were fixed on by bolts. Another set of steel tires by the Sandviken Foundry had run about 200,000 miles, with scarcely any signs of wear. The mode of attachment in that case was by a bolt from underneath, penetrating a short distance into the inner surface of the tire. Some steel tires by an American firm had run 309,000 miles, and were not much worn. They were on paper wheels in Pullman's cars, and had been running nearly nine years. The mode of attachment was by bolts passing through the paper of the wheel. The wheel was made of solidly compressed paper, and it appeared exactly like wood. It was formed like a wooden wheel, only the nave and the tires were of metal. Some other wheels used in the United States had afforded very good and even remarkable results. The tire was supported upon a series of blocks of hickory, driven in between the felloe and the tire of the wheel. The blocks were so driven in as just to support the tire, and to keep it free from touching the felloe. The results in point of mileage were remarkable. He thought, therefore, that the chief point for consideration was how to cushion the tire on the wheel, and how to improve the material of the tire, rather than to limit the mileage to be run by the wheels.

Mr. ROCHUSSEN said ten years ago he had presented a Paper to the Institution[1] giving a number of tabular statistics as to the wear of corrugated disc wheels, such as were in general use in Germany and other portions of the Continent. It was then proved that they had a life exceeding 398,000 miles, whilst now, such improvements had been made, that the Bochum Steel Works were enabled to guarantee that the life of these wheels should not be less than 500,000 miles. The plan adopted was to cast the centre and the tire in one, so that there was no question as to how the tire should be fastened. If in the end the tire should be worn out, there was no reason why the centre should not be treated as an ordinary wheel centre, and another tire be shrunk on. The same form was afterwards adopted by the Hoerde Works, and it had been largely introduced throughout the German system,—a wrought-iron centre with a puddled steel or cast-steel tire shrunk on, and screwed on from the inside. The latter form was at first found to be cheaper, but now that cast steel was so low in price, there was no necessity to make two separate parts. He believed that the cast-steel wheel now made in this country as well as in Prussia would be the wheel of the day. It seemed hardly dignified, after so many years' experience, still to think of the cushion of a tire, when the tire and the wheel could so well be made in one.

Dr. **Pole** said the members were much indebted to the Author, who had brought a good deal of thought to bear upon a very obscure subject, and his statements were worthy of careful attention. The facts mentioned with regard to the elongation were well known to those who had had an opportunity of observing and examining old tires. The result of the long wear was such that as the tires became thin, all tension ceased, and they actually became loose, assuming a form of section convex to the tread. In regard to the explanation given by the Author of the cause of fracture, there appeared a difficulty, for if it were true, then more tires ought to break. If statistics were given of the number of tires in use, it would be found that the proportion of those that broke was exceedingly small; but the force referred to as occasioning fractures was going on so constantly, that if the Author's explanation was correct scarcely any tire ought to stand. That the force might operate to some extent was undeniable, but the fact of its not acting more generally required some explanation.

Mr. E. **Riley** thought that engineers should pay more attention to the material of which wheels and tires were made, and to the influence the various chemical ingredients had on its quality. He was aware that little confidence was placed in the composition of steel. With regard to wrought iron the question was no doubt chiefly one of mechanical treatment: the iron might be chemically good and mechanically bad. But he believed (and the belief increased with his experience) that the elements found in steel had a marked effect upon the quality. He wished to warn engineers against drawing wrong conclusions on insufficient grounds. He would illustrate his meaning by a case that had recently occurred. He had examined a steel rail, and had found that it contained 0·2 per cent. of sulphur. He could not believe it, but on trying again, the result was the same. The fact was at first doubted at the works, but it was found to be as he had stated. The rail was, he believed, a good one, and an engineer would naturally say, "If you have a good steel rail with 0·2 per cent. of sulphur, what has chemical composition to do with it?" In the manufacture the difficulty would be in rolling. At a high temperature it would be possible to roll it and make it a good rail, but the manufacturer would find a great waste in such rails by ripping and tearing. In all cases of fracture it should be ascertained whether there was anything wrong in the material of the tire or of the rail. He thought that in many instances the material itself might be faulty. He quite agreed that the physical condition of the steel was an important matter. In the case of tires the exact quantity of carbon in each should be ascertained. Engineers might say that they could tell by turning a tire whether it had too much carbon; but he was of a different opinion. The tire might have been cooled slowly, and might contain a good deal of carbon. A great deal depended upon the mode of cooling, especially in rails. He thought that the cause assigned by the Author for the fracture of tires was a very probable one. He hoped that these matters would be investigated thoroughly, and that when failure arose from defective material, it would be attributed to that cause. He was certain, with regard to a rail taken from the Metropolitan line, it might last, yet if submitted to any sudden shock, it must, from its composition, necessarily break.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 430.

Mr. J. BAKER said he quite agreed with the Author as to the wearing of the outside of tires. In turning up old wheels their outside was sometimes found to be very hard, owing to the compression received during running in contact with the rails, but after getting through the skin the metal was much softer. The chief defect in iron tires was their splitting owing to insufficient welding, they being rolled in a straight bar and bent round in a coil. Some of them were not sufficiently heated for welding. Being worked in a hollow tool caused the edges of the iron to lap outside, and the punch to fill the seams up inside, so that it was impossible to see whether the iron was properly welded, and the compression and bulging of the outside of the tire through running made the defective or unwelded seams give way; but no doubt by this method a strong tire was obtained as regarded tensile strength, the fibre of the iron being the right way to avoid breaking. He believed that frequently the breaking of iron, and especially of steel tires, was owing to tight hooping; some tires were hooped almost to their breaking strain, so that the first sudden shock ruptured them. In many instances his attention had been drawn to the matter, by the spokes or arms of the wheels being bent out of shape by being hooped too tight, and in some cases, when the wheels had been strong ones, a sharp blow with a 12-lb. hammer had broken the tire.

Mr. THORNYCROFT said the cause assigned in the Paper for the breaking of tires, though not perhaps so important as the Author believed, was one that had been somewhat overlooked. A steel plate, 3 inches thick, 8 feet long, and 2 feet wide, would bend materially by the work of an ordinary hand hammer in a month's time. His firm had employed workmen to flatten steel plates on a steel slab of those dimensions, and it had been the custom to turn the slab over in order to retain a somewhat flat face. The slab was alternately bent one way and another. The insignificant force exerted by a man's arm working on the slab seemed incapable of effecting the amount of bending which it really caused. He differed from the Author in regard to the proposed limitation of the life of a tire to a particular mileage. He believed that the life depended more on the quality of the steel or iron employed than on the mileage run.

Mr. RICH said he knew nothing of the working or wearing of railway tires, but he believed that the action referred to by the Author might take place in other things with which engineers were concerned, and notably in the case of toothed wheels. The surfaces of toothed wheels were subject to more rubbing than tires; an enormous pressure was localised upon a small surface of a tooth in contact, and there was some initial impact, and it might be that teeth were sometimes broken from the gradual extension of their surface under the combined influences of bruising and hammering, and the consequent tearing asunder of their internal parts.

Mr. J. W. **Barry** thought the great local stress brought upon tires had scarcely been sufficiently considered. A weight of 8 tons often rested on a wheel, and as there was but a small portion of metal in contact, the local pressures between the tires and the rails were far in excess of what occurred in any other mode of applying iron. Taking a breadth of 1½ inch or 2 inches tread in contact at one time, it could not be assumed that there would be more than ⅛ or ¼ inch in width in contact, and under such circumstances there would be a stress of from 20 to 30 tons per square inch. This was the case when the rails and tires were new, but the action was of course increased with worn tires working upon a new rail. Then even smaller portions came in contact, and extremely great local stress was exerted. He thought it was quite possible that that action might account for some of the failures taking place in such unexpected ways, and at unexpected places. The rail also might be worn in a particular way, so that even with a new tire there might be extreme stress at particular points; and if such pressures were exerted from time to time, the action to which the Author had alluded, of the hardening of the surface of the rail, might be much aggravated. He thought it was extremely important that tires should not be fastened either by bolts or by rivets; for, as the Author had pointed out, an uneven surface was produced, which in spite of the supposed diminution of strain at the rivet or bolt-hole, must lead to an increase of pressure on each side of the hole. Tires running over such points, although wearing away rapidly, would from time to time be exposed, he thought, to greater strains than if the continuity were unbroken. He did not suppose that it would ever be possible altogether to get rid of broken tires; and the important point to be attended to was to keep the broken pieces on the wheel, so as to avoid the serious accidents that happened from such pieces flying out. A short time ago the traffic superintendent of a railway company told him that an express train, which had not stopped anywhere on its journey, entered a station 60 miles from its starting point with the tire of a carriage wheel broken in four places, and the wheel had run on without any one being aware when or where the accident had happened. The wheel was furnished with the well-known continuous ring fastening. If that tire had been fastened by bolts, the probability was that a disastrous accident would have occurred. It was of the greatest importance not to neglect such simple precautions, and to get rid of bolt and rivet fastenings for the tires of railway vehicles.

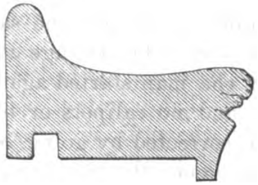
Mr. J. **Cochrane** said, in any limitation of the life of a tire to a certain mileage it would be absolutely necessary to take into consideration the speed at which the wheel had been running. If it ran at a high velocity with a light weight, it would be much the same as running at a lower velocity with a heavy weight. With regard to Captain Galton's remarks as to the mileage run by some of the tires on American railroads, it should be remembered that the average speed of trains in America was much lower than in England, and the same might be said with regard to the German railways.

Mr. L. H. **Shirley** was surprised to hear that the least number of breakages occurred in the months of January and February. He had had some experience in Russia, where the state of things was exactly the reverse, the greater number of breakages being invariably in the winter. On one occasion, on the 3rd of February, 1872, a train started from St. Petersburg to Wilna. In the afternoon there were only a few degrees of frost, but towards the evening the temperature declined to $-35°$ Fahr. In the course of the journey three carriages had to be taken off the train on account of broken tires, and on ascending the steep incline up to Wilna the steel tire of the engine broke. It had been found that wooden wheels answered best in that country, being attended with the fewest breakages. With the ordinary wheel the breakages were numerous, and hardly any great frost occurred without many of the lines being blocked, in consequence of accidents to trains arising from this cause.

Mr. **Beaumont** exhibited two sections cut from tires, by permission of Mr. W. Adams, M. Inst. C.E., showing plainly the actual transverse curvature that he had described. In reference to the remarks of Sir John Hawkshaw, as to wheels running only a certain number of miles, he did not say that tires should be thrown away, but that after running a certain number of miles they might be taken off and either re-turned or heated, so that the strains due to compression might be dissipated. As to new tires breaking, he had stated in the Paper that if strains from other causes tended to break the tires, such as by shrinking the tire on, it would in that case break when new rather than when old, because the effect of running was to lengthen the tire, and so to reduce the strain thrown upon it by shrinking it on. The same would apply to the observations made by Captain Galton, whose remarks, on the durability of cast iron, tended to support what he had said as to the durability of chilled surfaces, and as to the crumbling away of pieces relieving the strains generated by rolling. With reference to the loosening of tires, he believed that a greater number would become loose but for the bending to which he had referred causing the tire to grip the wheel. After a tire had run a certain number of miles it became worn, and the rim of the wheel was also partly worn, to the new form of the tire. If the tires did not tend continually to assume the transverse curvature described, they would become larger in diameter at *x*, *x*, as well as at *v* (Fig. 2), and would soon become loose; but as it was they gripped the rim at the points shown in the figure.

With regard to the remark of Dr. Pole, as to the reason why a greater number of tires did not break, he thought it was not difficult to give an explanation. A great many tires, after running for some time, not only became curved tranversely, but were irregularly deformed, by the detrusion of the material at the tread (Fig. 4), and in that way the strains were dissipated. But in the case of material that was too hard to give way in that manner, the strains were accumulated, and tended to break the tire. Mr. Barry appeared to misunderstand what he had said as to the strain near a hole in a tire fastened by bolts. It appeared that of the 477 cases of fracture mentioned in Captain Tyler's General Report for 1875, in which the tires were fastened by bolts, only 19½ per cent. broke through the holes, showing that the strain round these was dissipated, because the material was there free to flow, its continuity being broken. As to the number of fractures in Russia during severe frosts, he thought that that result was due, not to a difference in the strength of the material of the tire, but to the difference in the hardness of the road during such frosts.

FIG. 4.



Mr. STEPHENSON, President, said he must confess that the discussion had not elicited so much information as he had hoped. It was well known by manufacturers that it was a failure not simply in one, but in a great number of important, though small, matters occurring at the same time, that caused the breakage of perhaps the best tires. He quite agreed with the remark that mischief frequently arose from hooping tires too tight; and even when they were so hooped, complete contact was not always obtained throughout the whole breadth of the wheel. He believed that the curvature referred to by the Author was not entirely due to the cause he had assigned, but that it arose in a great measure from the web or spokes of the wheel not being so wide as the tire, the edges being therefore inadequately supported. He believed if the spokes were as broad as the tire, the curvature would be considerably reduced. Another important point had lately engaged his attention in preparing a wheel for the tire. Many persons must have noticed the difficulty there was in getting tools for cutting steel to stand. It was also known that the speed of the wheel on the cutting surface had to be kept low comparatively with the hardness of the metal. It was often found necessary to take a fine cut with hard steel, and sometimes, no matter how well the tool was tempered, a cut was lost. The instrument became at last slightly blunted, and instead of cutting, it was apt to spring and grind; and it was impossible, however experienced a man might be, to get the same cut with the tool after it had once been lost. The change could be easily observed with a microscope. If the man started again, a hollow or a raised surface would be left, and no calipers or templates would set it right. This might be corrected by going over the whole surface with another cut, but generally this could not be done, as the wheel would then be too small. He approved of a cushion between the tire and the boss of the wheel, and he had a strong preference for wood.

November 28, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,461.—"The Chalk Water System."[1] By JOSEPH LUCAS.

HYDROGEOLOGY, a term first used by the Author in 1874, takes up the history of rain-water from the time that it leaves the domain of the meteorologist, and investigates the conditions under which it exists in passing through the various rocks which it percolates after leaving the surface. A hydrogeological survey comprehends an examination of all facts relating to the form and position of subterranean water systems, their capacities, variations, channels, and directions of flow; and, in basins where they are covered by superincumbent strata, the extent to which they are siphonised, or the height to which the water will rise on being liberated by a boring. These heights, taken in conjunction with the surface contours, determine the geographical position and extent of the areas of overflow in Artesian districts. The Author has been for some time past engaged upon such a survey, which, though a purely scientific investigation, may nevertheless lead to results that cannot fail to alleviate one of the most pressing wants of mankind. Hitherto a great diversity of opinions has prevailed in regard to the capabilities of the Chalk Water System, but it is doubtful whether any observations can be produced which throw direct light upon the question of quantity.

The Author is aware that many observations have been made having a more or less direct bearing upon the subject, but most of them are too fragmentary to be of service, and all leave out some essential particulars, without which the others are comparatively useless. The oldest series of well measurements known to the Author is that of Mr. W. Bland, of Hartlip, going back to 1819, and published about the year 1830, and the next is that of the Rev. J. C. Clutterbuck, who made a series of measurements on the chalk hills of Hertfordshire about the year 1841. Besides the above, there is the valuable well register kept by the late Mr. Leyland Woods, and his son, Mr. J. W. Woods, at Chilgrove, from 1835 to the present time (Table 3 in the Appendix). The Author is not aware of any extensive series of observations having been made, on the variations in the height of the water-line in the Chalk by means of open draw-wells. There are many registers of wells in which there are pumps, but these are only of secondary importance when compared with observations on the undisturbed waters of draw-wells, though of the utmost value when the effect of pumping has to be considered.

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[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

The observations of the Author extend over four years, and range over about 200 square miles of country, on which almost every accessible well has been measured. The measurements number many hundreds. The wells are distributed with fair regularity over the area, and are sufficiently numerous to enable accurate hydrogeological sections to be drawn. The object of the well measurements is to determine the limits of the water-line, for it is not until a large number of observations have been obtained that approximations to these positions can be arrived at.

From the data thus gained the Author has been enabled to compile the following account of the Chalk and its waters, for which he claims that it is not only the most complete, but also that it is the only correct one that has appeared. The well measurements would have been valueless without the contoured 6-inch Ordnance maps. With the assistance of the data given on these, the height of the mouth of each well above Ordnance datum has been estimated or measured, and the construction of hydrogeological maps and sections has been rendered possible.

In addition to well measurements, which indicate the form and position of the water-line, there are also available the valuable registers kept at Lee Bridge since 1851 by Mr. C. Greaves, M. Inst. C.E., and the long-continued register of the quantity of rain passing into the Chalk, as measured in percolation gauges at Nash Mills, Hemel Hempsted, by Mr. John Evans, Assoc. Inst. C.E.[1] Without discussing the merits of these particular registers, the information at which they aim is an important factor in the calculation of the capabilities of the Chalk and other water systems.

The information given in this Memoir is the result of a hydrogeological survey of the chalk hills forming the North Downs of Kent and Surrey, and lying between the rivers Wey and Darent. The Chalk rises from under the Tertiary beds of the London basin by a long inclined plane, terminating in a ridge, or escarpment, which presents a steep face towards the south. This long northerly inclined plane is grooved by several systems of dry valleys, from which, at the points where they are cut off by the Tertiary beds, there spring the Cray, the Ravensbourne, the Wandle, the Hog's Mill River, and the Clandon Brook. The chalk escarpment consists almost entirely of the Lower Chalk, the Chalk with flints being frequently absent, and never constituting more of the escarpment than its summit. The valley systems on the northern side of this elevated ridge attain their maximum depth within a mile or so of the escarpment, after which they decline in depth until they disappear altogether at the Tertiary base. The upper parts of these little basins are cut deeply into the Lower Chalk, the Chalk with flints capping the ridges on their confines; until, the northerly dip of the beds being considerably greater than the fall of the ground, the lower parts of the valleys are cut wholly through the Chalk with flints.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., pp. 19 and 208.

The elevation of the chalk escarpment varies from about 200 feet at the Wey, the Mole, and the Darent, to 880 feet north of Oxted.

Between the Wey and the Mole the chalk escarpment ranges—

Above	700	feet for	2	miles out of	10
„	600	„	6	„	10
„	500	„	7½	„	10
„	400	„	9	„	10

Between the Mole and the Darent it ranges—

Above	800	feet for	2½	miles out of	22
„	700	„	13	„	22
„	600	„	18	„	22
„	500	„	21	„	22

The form of the ground above described has a marked effect on the quantity of rain falling at its extreme positions. Thus the rainfall on the escarpment at the Denbies is 17 per cent. higher than that at its foot, and 37 per cent. higher than that at the foot of the northern slope at Croydon.

Rain falling on the Chalk, where it is not covered by clay, sinks until it reaches a body of water previously accumulated in the same manner, which body of water is maintained in its present position by the boundaries of the Chalk Water System about to be described. Wells in the Chalk have to be sunk to this water, through any thickness of dry chalk that may intervene. The greatest thickness of dry chalk so traversed in the Author's experience somewhat exceeds 320 feet. Rain thus absorbed is subsequently disposed of by direct outflow from springs, which either flow over the Tertiaries, or under them, subsequently escaping into the sea; or, when the Chalk comes to the coast, direct from the Chalk into the sea; and it is the sole source of the water in the Chalk. This fact is exhibited by the records of the monthly rainfall at Hemel Hempsted, the depth of rain absorbed, and the variations in the height of the water in the well at Chilgrove, Sussex. Though the two places are separated by a distance of 60 miles in a straight line, the rain recorded as absorbed at Hemel Hempsted is abundantly sufficient to explain the changes in the well at Chilgrove. The ratio of the part absorbed to the total rain varies in respect of two particulars. 1st. If on different occasions a given quantity of rain falls within a given time, a much larger percentage may be absorbed from one fall than from another. 2nd. In different localities, at the same date, the ratio of the part absorbed to the total fall is liable to vary considerably.

The Chalk Water System has for its ultimate hydrogeological boundaries the Chalk Marl at the base of the Chalk, and the argillaceous base of the Thanet sand, where it exists, and where there is no Thanet sand, of the Woolwich and Reading beds, above the Chalk. The thickness of the Chalk Marl is about 50 feet over the area under description. In its lower part the Chalk Marl is a bed of grey clay. Though passing upwards into the Lower Chalk, it may be regarded as an inclined plane upon which the water in the chalk above ultimately rests. The existence of water in the Lower Chalk is characterised by great uncertainty. It is probably more of a water-bearing stratum where exposed in the above-described valleys than when covered by the Upper Chalk and the Tertiaries. It appears to contain few fissures, and to be characterised by the presence of vertical fissures which sometimes become cavernous. The Upper Chalk, on the other hand contains many small fissures primarily formed in the plane of the bedding along the layers of flint, but also making various angles with that plane. Thus, the water in the Lower Chalk exists as distinct streams, having the ordinary tendency of surface streams to unite, while that in the Upper Chalk flows down its myriad crevices, like the threads of a spider's web. When these streams are cut in a well, they are called feeders.

The water in the Chalk nowhere exists as a voluminous mass; each little stream is regulated by the fissure that contains it. Taking the Chalk as a whole, the fissures vary in size from a pin's head to a cavern large enough to contain a man, and the feeders range from the minutest jets to considerable streams. Wells in the Lower Chalk are the more readily exhausted, as, from the moment at which the water-line is lowered by pumping, an inverted cone is formed, and the gross capacity of the fissures in this cone would presumably be greater in the Upper than in the Lower Chalk.

The "water-line" is the name given to the upper surface of this water in the Chalk. It may be ascertained by observing the height at which the water stands above Ordnance datum in open draw-wells, and joining the points thus determined on a section. Not every fissure cut by a well below this line is water-bearing. It is easy to conceive, in explanation of this, the existence of independent systems of fissures, isolated from those to which rain-water finds access.

Wells sunk for the supply of single houses, and which have the good fortune to meet with water-bearing fissures, need only be carried a few feet below the water-line; but where larger quantities of water are required, a greater distance has to be traversed before the united contributions of all the fissures are sufficient to supply the demand. It follows that the water-line must be locally depressed, to the extent of the depth it has been necessary to go below its natural position, to obtain this amount, as long as the quantity in question is drawn from the well, and, where more is required, it is necessary to lower the point of outdraught. These considerations should demonstrate the futility of attempting to substitute a boring for a shaft, on the chalk hills, or in any position in which dry chalk has to be traversed, before reaching the water-line.

The upper surface of the water in the Chalk, as gathered from numerous transverse and longitudinal sections, is a long inclined plane, terminating against another inclined plane, that of the Chalk Marl, which slopes in the same direction, but at a greater angle. Where the inclined plane of the water-line abuts against the Chalk Marl, there is the boundary, in a southerly direction, of the water in the Chalk. The inclined plane of the Chalk Marl continues to rise for a long distance after, and to a great height above, this line of abutment.

There is therefore a considerable strip of chalk in which there is no water. The width of this strip varies with the vertical oscillations in the height of the water-line in the Chalk—a rise being accompanied by a southerly advance, and a fall by a northerly recession of the line of abutment. The variations in the height of the water-line define the limits of deviation in the position of the line of abutment, which never rises so high or approaches so near the escarpment as to pour springs over the Chalk Marl into the Weald, except in the case of two permanent springs. In the 36 miles of chalk escarpment between the Darent and the Wey, the only springs that the Author has found flowing out of the Chalk over the Chalk Marl into the Weald are those at the Sherbourn Ponds and the Brockham Lime Works.

The Author agrees with the Rev. J. C. Clutterbuck, that the water-line is ultimately dome-shaped in all cross sections joining two opposite springs; but he has found that in transverse sections intermediate and parallel to these, the water-line rises by an inclined plane, above the summit of the dome on the first-mentioned lines, and terminates against the impermeable inclined wall of Chalk Marl.

A longitudinal section between two transverse rivers exhibits the water-line rising from both rivers, and having ultimately a long gently-curved outline. The contour lines on the water surface approximate to the strike of the beds when there are no large valleys, but sweep back round the main valley systems, returning to their normal position under the alternate ridges (Plate 3). The great bays in the water contour thus formed are two in number on the area between the Darent and the Mole, not counting those caused by the valleys of the Darent and the Mole. The result of these bays is, that in a longitudinal section the water-line presents a series of long low-crested waves, of which the summits represent the water-line at its natural height, and the hollows the extent to which it has been lowered locally by the operation of fissures, under, and along the lines of, the main valleys, acting as deep drains. The original maximum and the original minimum water-lines in these bays are therefore lost; but their positions may be approximately arrived at, by joining the horns at either extremity of the bays mentioned, by lines parallel with the strike of the beds.

The height of the water-line in all parts of the Chalk Water System is subject to alteration. Its variations follow the rainfall. The rule may be thus stated:—The tendency of the water-line is to rise and fall parallel to itself; but the springs at the Tertiary base being fixed points, and the main ridge of the chalk escarpment the source of greatest supply, in respect of a cross section the line vibrates from those fixed points, the amplitude of the vibration being greatest under the source of greatest supply. This is referred to as the natural variation. Generally, the water-line lies between these two limits, at heights dependent upon the ratio which the supply by rain absorbed bears to that required to maintain the water-line in its minimum position (Table 5). The total storage capacity of the Chalk drawn upon in nature lies between the two lines bounding the sectional area of variation. The vertical range of the water-line determines the horizontal range of the water contours, which attain their most northerly position at a maximum epoch, and their most southerly at a minimum epoch.

It does not follow that the water-line over an area varies everywhere in the same ratio between the same times. For instance, while certain wells, under the points of greatest supply, had made 30 feet of water between November 1874 and May 1875, others, lying low down on the northern slope, had not gained anything, and one or two had even lost some of their water. It is nevertheless true of limited areas, that the water-line varies in the same ratio between the same dates.

The amount of variation in the height of the water-line is greatest, in the Lower Chalk, under the deep valleys springing from the highest ridges of the chalk escarpment, near the point of chief supply. This general cause is aided by a local cause, viz., large vertical fissures, the existence of which under the deep valleys of the Lower Chalk, as at Caterham, is inferred from the water falling much lower at minimum periods beneath these valleys than under the intermediate ridges. While it falls so low, the water in these positions can never rise even to the original minimum, found by the process described above, since the surface contours run back into the area of the bays, presumptively generated by fissures. In other words, the original minimum water-line, if restored, would stand at a higher level than the modern bed of the valley. The modern bed of the valley is so deep, that there is not room between it and the present minimum water-line for the full natural variation to have play. The bed of the valley forms in fact the attainable maximum, and the consequence is, that whenever the supply by rain exceeds the amount required to raise the water-line to this height, the excess flows down the bed of the valley as a stream or bourne. This species of bourne is a phenomenon characteristic of, and due to, the Lower Chalk. The water that rises above the surface may, and sometimes does, sink again on reaching the Upper Chalk, as at the Red Lion at Smithambottom, and in the Austin valley, so that there is a surface stream in the upper part of the valley, and not in the lower. This surface stream flows farther than it would otherwise do by reason of a clayey detritus that forms the bed or soil in the valley. Instances of the occurrence of such bournes, originating in the Lower Chalk, are as follows.

According to an account in "The Times," the water rises above the bed of the Caterham valley, and flows as a surface stream, on the rare occasions on which the rainfall at Croydon exceeds 30 inches in the previous twelve months, or when that on the chalk escarpment near Caterham (by raising 30 inches 22 per cent., Table 1, second part) exceeds 36 inches.

Modern instances are—

1841,	when the	rainfall was	33·3	inches.
1852	„	„	34·2	„
1866	„	„	32·0	„
1873	„	„	36·72	„

"In 1866 the bourne appeared at Caterham in the first week in February. On the 10th of that month it began to flow under the railway bridge at Caterham Junction."

"In 1873 the earliest indication of the rise of the bourne was in the first week in January, when it was noticed that the water in a well at Caterham increased in depth 2 feet in eight hours. About the 12th of January it rose to the surface, and began to flow copiously down the Caterham valley towards the railway bridge."

In the first week in February 1873, a bourne came out of the Merstham tunnel, and flowed down the Croydon valley as far as the Red Lion at Smithambottom, in the garden of which establishment it sank. The water in the well at the Red Lion remained at some considerable depth from the surface. This bourne did not disappear till the last week in May, according to the testimony of the landlord.

In Kent, east of the Darent, in July 1874, a bourne broke out in the Austin valley below Romney Street, and flowed down the valley with great violence, demolishing a wall and doing other damage to the farm-buildings at Upper Austin Lodge. The water in the well at Upper Austin Lodge remained at a great depth from the surface: the water sank below the surface lower down the valley.

While the bournes of 1873 were rising in the Lower Chalk, a series of phenomena due to the same general cause—excessive rainfall—but manifested in a slightly different way, were exhibited in the intermittent springs, thrown out from the upper chalk by the base or boundary of the Tertiary beds. Instances of this occurred between the months of February and July at Cheam, Epsom, and Little Bookham, and water rose into chalk-pits at Sutton, Cheam, and Clandon Park.

Since the variations in the height of the water-line are the results of excess or defect in the rainfall, it follows that the water-line in every position has an appropriate quantitative value. In viewing these variations over a series of years, a correspondence is observed between the ratio of the mean height of the water-line during each year to the mean water-line for the whole period, and the ratio of the rainfall of each year to the mean annual rainfall of the whole period. A closer correspondence might be expected between the same ratios in the case of the depth of rain absorbed. It will appear from Tables 4 and 5 that those taken at Nash Mills, when increased in the ratio of the excess of the rainfall at Chilgrove over that at Hemel Hempsted, do go a long way towards explaining the facts chronicled in the Chilgrove well register.

It has already been stated, that the height of the water-line above the minimum depends upon the ratio which the supply by rain absorbed bears to that required to maintain the water-line in its minimum position. Now this latter quantity could only be obtained by calculation. But the mean rainfall, and the mean amount absorbed are known—those quantities being observable, as opposed to the amount required by the minimum, which is only calculable—and the mean height of the water-line is also known. Further, the mean water-line is the net result of the mean depth of rain absorbed; therefore, for these reasons, it is more convenient and more certain to take the mean water-line as the basis of calculation than the minimum.

In November 1874, a well at Bughill Farm, in the Marden valley, which overflows when the bourne is flowing, and which is 125 feet deep, was quite dry. The amount of variation proved at Bughill Farm is 125 feet, though it may exceed that amount, and higher up the valley it probably reaches 140 feet or thereabouts.

There are no data for calculating the mean height of the water-line at any point in this part of the valley, or of the water system anywhere on the area under consideration; but there are ample details for exhibiting a method of calculating such particulars furnished by a long register of the depth of water in a well at Chilgrove, in Sussex (Table 3). This well is similarly situated, in respect of physical features, to wells in the Lower Chalk, such as that at Bughill Farm; so that conclusions drawn in reference to the well at Chilgrove will apply equally to wells in the Marden and Caterham valleys. The Chilgrove well is in a valley, in the chalk hills, which in most years has a surface stream. The hills rise 200 to 500 feet above it. The depth of the well is 145 feet, and the height of the well-mouth about 266 feet above sea-level. Although the register dates from 1836, the period treated includes only the eight years 1853–1860. For a register of the depth of rain absorbed, that of Nash Mills is adopted, as approximately correct. The mean depth of water is 41 feet, and the mean depth of rain absorbed is 6·58 inches. The minimum depth of water is 5 feet, and the mean position of the water-line is 36 feet above the minimum. To calculate the mean depth of rain absorbed, necessary to maintain the water-line in its minimum position, there are the following data. On two occasions the water stood at 40 feet, or 1 foot below the mean—once as a minimum and once as a maximum. When a depth of 40 feet was a minimum, the water rose 58 feet in ninety-two days—from 40 feet to 98 feet. By calculation 2·9 inches of rain were absorbed before the rise ceased, and this quantity for ninety-two days gives a mean daily value of ·032282 inch absorbed—

$$\begin{array}{rl} \cdot032282 \times 365 = & 11\cdot78 \text{ inches.} \\ \text{Subtract} & \underline{\;6\cdot58\;} \end{array}$$

Which gives 5·20 inches as the difference between the mean depth of rain absorbed annually (or the quantity necessary to maintain the water-line in its mean position), and the annual equivalent of the quantity which raised the water from 40 feet to 98 feet above the bottom of the well. But 98 feet above the bottom of the well is 57 feet above the mean position of the water-line, and the mean position is 36 feet above the minimum. Then, if x = the difference between the average amount absorbed (6·58) and the quantity necessary to maintain the water-line in its minimum position,

$$\frac{x}{5\cdot2} = \frac{36}{57}, \text{ or } x = 3\cdot29 \text{ inches.}$$

And 3·29 subtracted from 6·58 leaves 3·29 inches as the mean annual depth of rain absorbed which would be necessary to maintain the water-line in its minimum position. The ratio of the quantity required by the mean to that required by the minimum is therefore as 2 to 1.

In the Chilgrove well the ratio of the maximum recorded height to the mean height above the minimum is 3·93. Therefore, assuming an equal rate of rise for equal increments in the supply at all heights, which is nearly true, the amount required by the maximum = 3·93 × the amount required to raise the water-line from the minimum to the mean position + the quantity required by the minimum. That is

$$3{\cdot}29 + (3{\cdot}93 \times 3{\cdot}29) = 16{\cdot}21 \text{ inches annually.}$$

Although it is nearly true that the water-line is raised equal heights for equal increments, at all heights between the minimum and maximum, it is not strictly so.

Thus, taking from Table 5, Part 1, four cases which give consistent results, and discarding the other three which do not agree, either with the four named or among themselves, it is inferred that each inch of rain absorbed—

Out of	With the Water-line at	—	Raised it	—
Inches.		Difference.	Feet.	Difference.
2·9	35 feet above the minimum .	14	20	7
3·48	21 " " " " .	12	13	3½
9·7	9 " " " " .	9	9½	1¼
8·7	at " " .		8¼	

Of the three inconsistent cases two agree in indicating a less amount of rise due to equal quantities absorbed than that shown by the four cases. It is not impossible that both results may be attained, a more rapid rise occurring when the rain to which it is due is general, than when it is local.

It is therefore obvious that the fissures must be worn larger where they are most washed than they are higher up in the well, inasmuch as the same amount of rain absorbed produces a greater amount of rise when the water-line is high than when it is low.

A depth of 16 inches may then be taken as the quantity necessary to maintain the water-line at the recorded maximum; or an equable flow of that amount would maintain the water at that height. The ratio which the quantity required by the recorded maximum bears to that required by the minimum is 4·86. The ratio which the same quantity bears to that required by the mean is 2·43. In the case of a well, such as that at Bughill Farm, which is in the bed of the valley, and overflows when the bourne is out, in consequence of the valley being so deep that the full natural variation cannot have play, the natural maximum can be estimated thus: by converting the quantity required by the attainable maximum into its equivalent value in feet, and increasing that height in the ratio of the greatest observed excess in the quantity absorbed over that required to maintain the water-line at the attainable maximum. This excess causes the surface stream or bourne to flow. The water-line in wells remote from such a valley goes on rising after the first appearance of the bourne, and attains its maximum position when the bourne has reached its full volume. Since the ratio of the quantity required by the recorded maximum to that by the minimum is 4·86, it may at present be taken roundly that five times as much rain as is necessary to sustain the minimum would maintain the natural maximum over any area; in other words, the flow would have to be increased 400 per cent. to raise the water-line from its minimum to its maximum position. In the period under consideration (1853–1860), the mean duration of fall in the height of the water-line was one hundred and eighty-one days, whereas the mean duration of rise was one hundred and sixty-five days, and the ratio of the mean duration of fall to the mean duration of rise was 1·09. In the longer period, 1853–1866, the mean duration of fall was two hundred and four days, and the mean duration of rise one hundred and forty-six days, which gives the ratio of fall to rise 1·4. This is due to the supply being delivered in large quantities, at long intervals, so that the fissures are filled quickly and drained slowly. Obviously, therefore, no interference should be permitted with the Chalk Water System that would tend to accelerate the rate of fall. The number of months during which the water-line stood below the mean in the same period (1853–1860) was fifty-five, and the number in which it stood above the mean was forty-one.[1] The ratio of the number below the mean to the number above was 1·3. The greatest consecutive number of months below the mean was thirty, viz., March 1857 to November 1859, and the greatest consecutive number above was eighteen, viz., from December 1859 to May 1861. The ratio of the number below to the number above was 1·6. The mean ratio of the part absorbed,

---

[1]

	Below.	Above.
1853	2	10
1854	8	4
1855	10	2
1856	5	7
1857	7	5
1858	12	0
1859	11	1
1860	0	12
	55	41

to the total rain at Hemel Hempsted during the rises, was ·342, whereas during the falls it was only ·174. The mean ratio of the rise in the water-line to the depth of rain absorbed that caused it was 118·3. This well, it must be remarked, is in the Lower Chalk, where there are no flints and few fissures; but the fact remains that the mean effect of the rain absorbed by the Chalk during the rises was to cause a rise of nearly 120 times its own depth.

From the above statements regarding the oscillations of the water-line, then, it is inferred—

1. That the mean duration of fall is half as long again as the mean duration of rise; or, in other words, in respect of any given period, during three-fifths of the period the water is falling.

2. During three-fifths of the period the position of the water-line is below the mean.

3. That the mean value of a rise in the water-line, at or near the point of maximum variation, is 120 times the depth of the rain to which it is due. It has also been shown that the total utilised storage capacity or reservoir lies between the maximum and minimum water-lines, and that the only practical effect of the water in the Chalk below the minimum is to maintain the reservoir at its present elevation. It follows, that if the water-line is at any time drawn below its natural position for the time —wherever that may be, whether maximum, minimum, or mean— on a given increment in the supply occurring, it will not again rise to the height naturally due to that increment.

In respect, therefore, of pumping on an extensive scale from deep wells in the Chalk Water System—

1. The tendency is to accelerate the natural rate of fall, and to retard, and in many cases to intercept, the rise.

2. To prolong the duration of fall, and that of the period in which the water-line is below the mean.

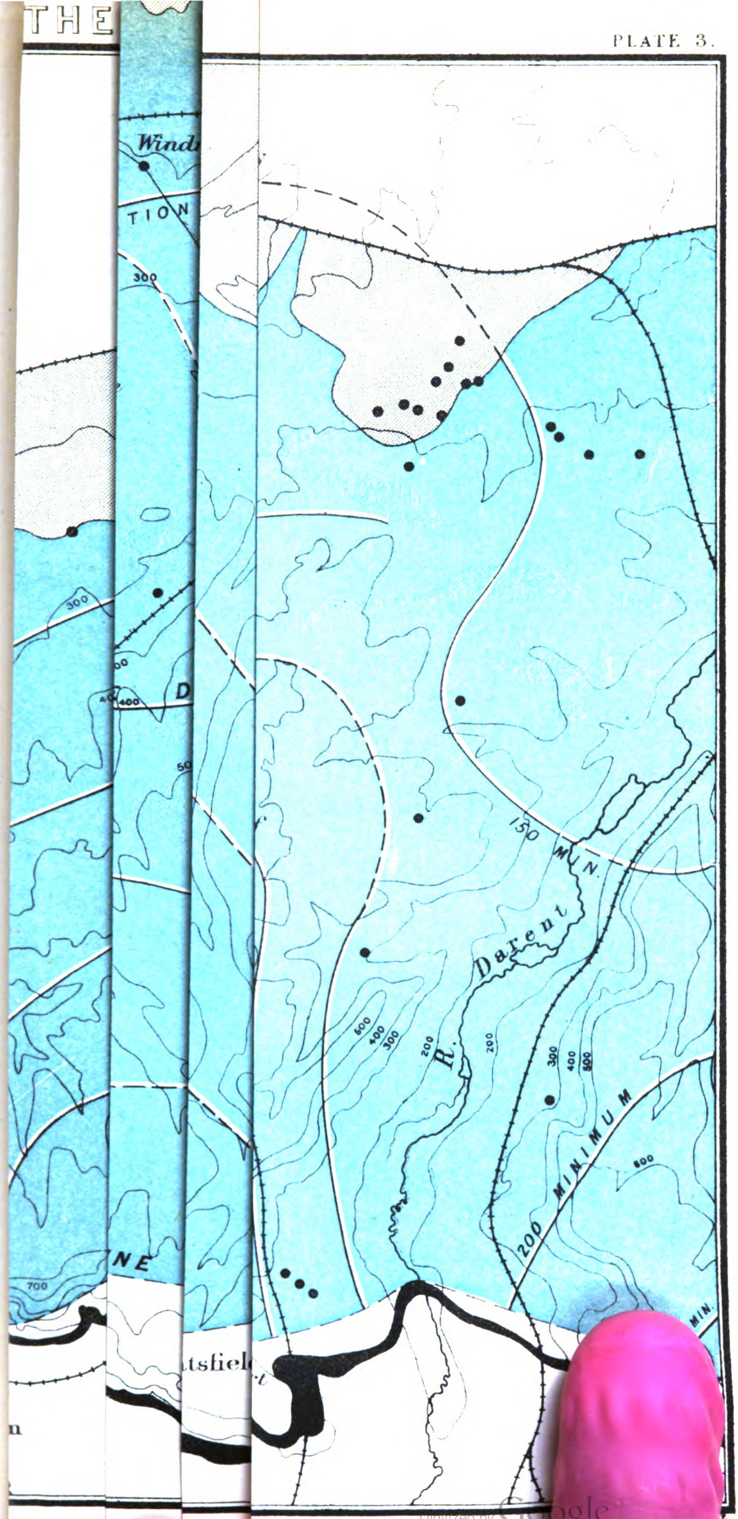
3. To lower the reservoir bodily, so as to establish a new system of water-lines, a new maximum, a new minimum, and a new mean water-line.

4. Nothing could more forcibly demonstrate the limited capabilities of the Chalk Water System, than the consideration that the ordinary gigantic fluctuations of the water-line represent a mere film of rain.

The communication is accompanied by a series of diagrams, from which Plates 3 and 4 have been compiled.

[APPENDIX.

PLATE 3.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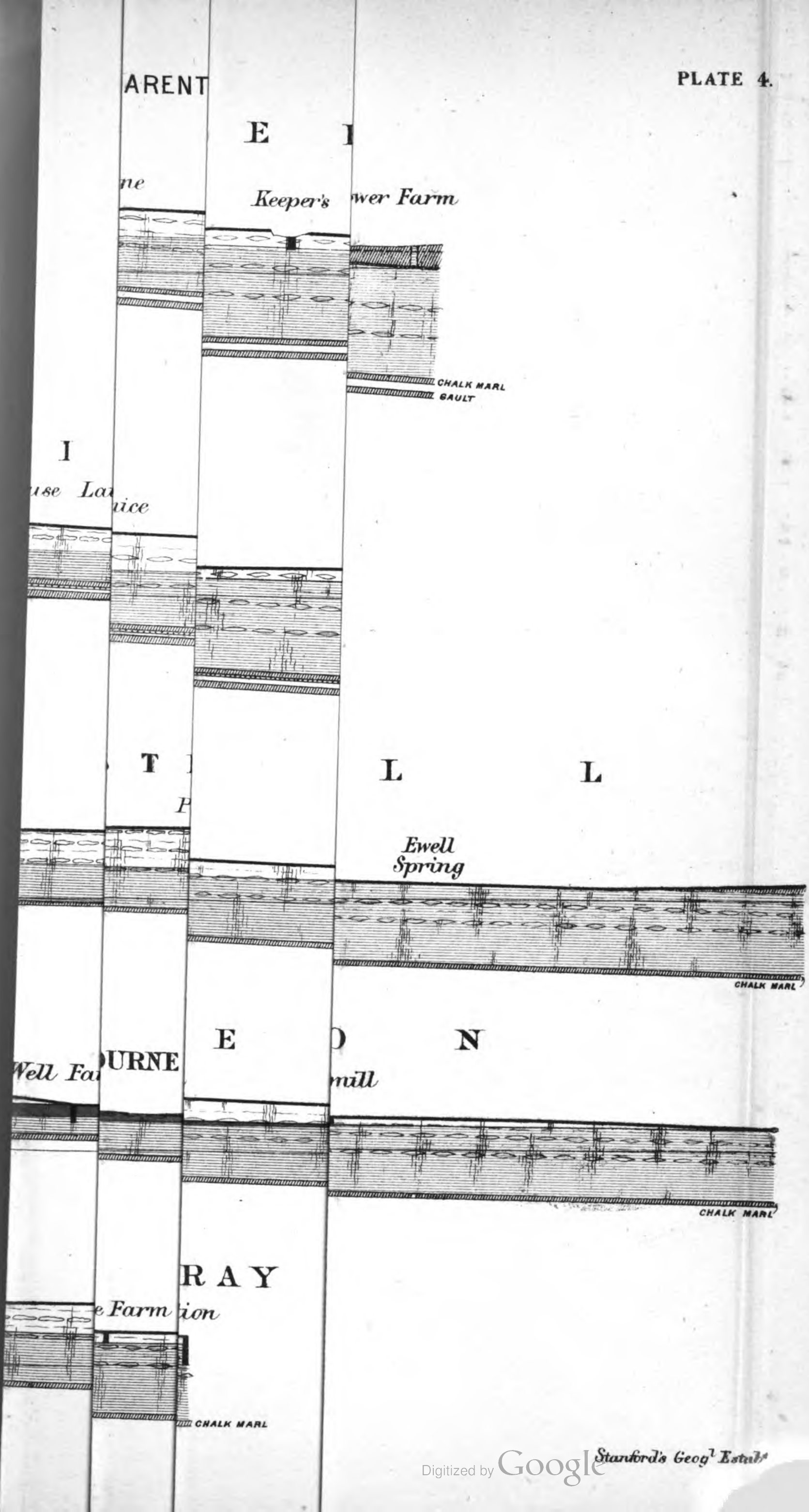
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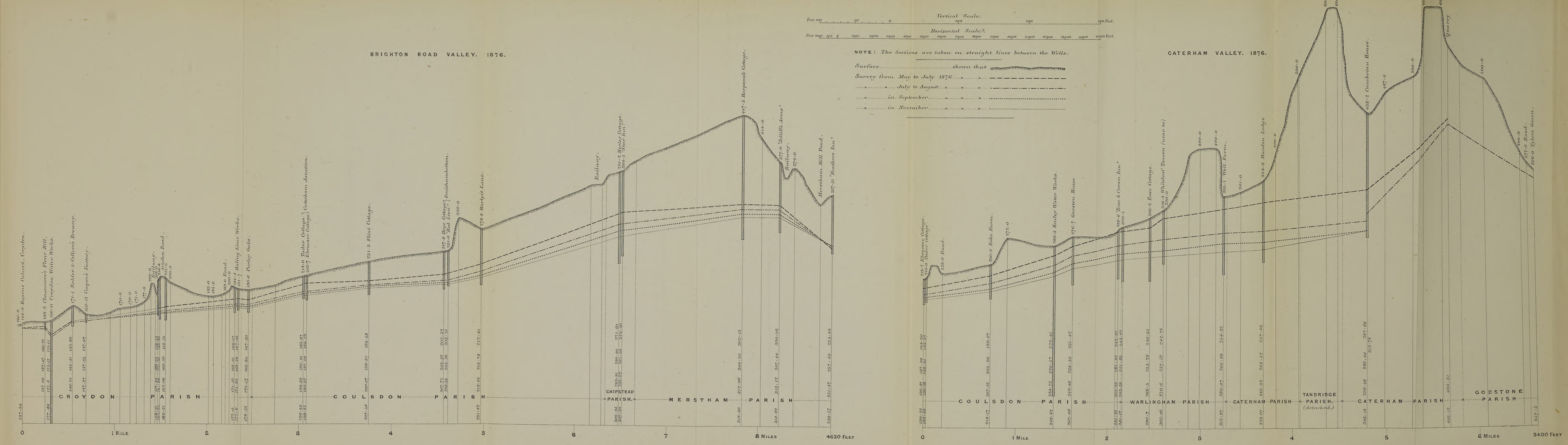
THE CHALK WATER SYSTEM.


Vertical Scale.
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Horizontal Scale.
Feet 1000 500 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10,000 11,000 12,000 13,000 14,000 15,000 Feet.
NOTE: The Sections are taken on straight lines between the Wells.
Surface shown thus
Survey from May to July 1876
" " July to August
" in September
" in November
BRIGHTON ROAD VALLEY. 1876.
CATERHAM VALLEY. 1876.
CROYDON PARISH
COULSDON PARISH
CHIPSTEAD PARISH.
MERSTHAM PARISH
WARLINGHAM PARISH
CATERHAM PARISH
TANDRIDGE PARISH. (detached.)
GODSTONE PARISH
Croydon Water Works.
Caterham Junction.
Smitham bottom.
Railway.
Jolliffe Arms
Feathers Inn
Merstham Mill Pond.
Kenley Water Works
Rose & Crown Inn
Harden Lodge
Quarry
Tylers Green.
0 1 Mile 2 3 4 5 6 7 8 Miles 4630 Feet
0 1 Mile 2 3 4 5 6 Miles 3400 Feet

BALDWIN LATHAM, DELT

Minutes of Proceedings of The Institution of Civil Engineers. Vol. XLVII. Session 1876-77. Part 1.

[illegible] 40, KING ST COVENT GARDEN.

APPENDIX.

EXPLANATION OF THE TABLES.

Table 1, drawn up from very scanty materials, shows the ratio in which rain falls on different parts of the chalk area. The first part of the table gives the simple registers, extracted from Symons' "British Rainfall." The second part shows: 1st. The average annual fall at each station for the period registered (in each case) in the first part; 2nd. The ratio which the average at Greenwich for the same groups of years (in each case) as those given in the first part bears to the average for the period 1815–1873; 3rd. The short-period averages given (in each case) have been reduced to long-period averages in the same ratio as Greenwich. The averages are then compared with that of Croydon, first, by taking the ratio which each bears separately to each of two separate gauges at Croydon, and then by taking the mean of these two ratios, which is placed in the last column as the adopted ratio. For instance, the ratio of the mean rainfall at Caterham to that at Croydon is taken at 1·226.

Table 2 shows the height of the springs breaking from the chalk at the base of the tertiaries, and of those from the base of the chalk.

Table 3 gives: 1st. The register of a long series of measurements, taken monthly in the well at Chilgrove, near Chichester. This has been collected from various sources; part of it has been supplied by the Rev. J. C. Clutterbuck, of Long Wittenham; part by Mr. Symons, and many parts by Mr. J. W. Woods, of Chilgrove, the owner, who still keeps up the register.

Table 4 is derived from the materials contained in Table 3. It gives the mean depth of water in the well in each of the years 1853–1860, and the mean for the period 1853–1860, the rainfall at Chilgrove and Hemel Hempsted, and the depth of rain absorbed at Hemel Hempsted. From these data have been calculated (column 11) the depth of rain absorbed at Chilgrove by taking the ratio of the part absorbed to the total fall at Hemel Hempsted, and diminishing the total fall at Chilgrove in the same ratio. (Multiply each line in column 4 by each corresponding line in column 10, which gives column 11.)

Table 5 is designed to investigate and exhibit at one view the reason of the rises and falls that actually took place in the water-line at Chilgrove. To simplify the subject, the rises are all treated in the first part of the table, and the falls in the second part. The first five columns give the actual facts as recorded in the register (Table 3) in relation to the amount and duration of each rise and fall; then follow the mean daily rates of rise and fall and of rain, the ratio of the mean daily rise and fall to the mean daily rain, then the total rain at Chilgrove during each rise and fall. But as the rises and falls are not directly referable to the mean daily rain, but to the mean daily quantity absorbed, the registered depth of rain and of rain absorbed at Hemel Hempsted are also shown, and from those data an approximation to the depth absorbed at Chilgrove during each rise and fall is calculated. In many instances the results are consistent, but it is not to be expected that the ratio of the part absorbed to the total fall should be the same in every instance in both places. The calculated amounts are then reduced to daily means, and the ratio of these to the mean daily rise and fall, and to the mean daily absorption required by the mean and minimum water-lines, and by the starting point, together with the ratio of the total rise and fall to the total depth absorbed, are given in the next six columns of the table. For instance, the most rapid rise recorded in the table is 93 feet in ninety-two days, starting at 14 feet above the bottom of the well, or 12·2 inches per day; and by consulting the table it will be seen that more than 5 times as much rain was absorbed daily as was required to maintain the water-line in its mean position, 11 times as much as was required by the minimum, and 9½ times as much as was required by the starting point. The next two columns give the mean depth of water in the well in each period and its ratio to the mean depth for the whole period under review.

Table 6 gives an approximation to the amount of seasonal variation in the height of the water-line on a part of the chalk water system between Epsom and Croydon. Some of the wells were measured when the chalk water stood at an extreme maximum position, and others were not. Again, some were measured when the water was at an approximate minimum, and others were not. In respect of this area of observation it may be taken as approximately true that the water-line varies in the same ratio between the same dates, and on this principle the extremes not observed have been calculated.

Table 7 is a closer investigation into the same points, and treats of a line of section about 1 mile long, close to the tertiary beds at Epsom, with five wells of observation. A fact brought out by the table is that the gradient on the water-surface is considerably steeper when the water-line is at a minimum than when it is at a maximum position. The tertiary base forms a long inclined dam, sloping from the wells of observation; consequently when the water is low, it abuts against the under surface of this inclined dam at a point more remote from the wells than when it is high. Use has been made of these facts in a recent Report to the Epsom Local Board of Health on the best means of increasing the supply of water to the Waterworks well. The works are situated a short distance in the tertiary area, at a point where the chalk is 62 feet from the surface. The shaft is 50 feet deep with a boring into the chalk, but the point of outdraught is only 43 feet deep, or 19 feet above the chalk. Owing to the abutment of the water-line in the chalk against the tertiary base being so near the Waterworks, the greater part of what should be the cone of exhaustion due to the pumping is occupied by tertiary strata. Therefore the actual reservoir drawn upon is small, and the springs are exhausted at 43 feet. The Board was therefore advised to deepen the shaft into the chalk, and to lower the point of outdraught.

Table 8 gives some old measurements of wells subsequently measured by the Author.

Then follow the Author's general tables of chalk wells.

TABLE 1.—RAINFALL on the CHALK ESCARPMENT.

Stations on the Chalk Escarpment.	Heights.			Depth of Rain.								
	Above O.D.	Above Ground.		1865	1866	1867	1868	1869	1870	1871	1872	1873
	Feet.	Ft.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
The Denbies . . .	610	1	0	..	..	..	..	..	..	33·35	45·28	31·01
Brookmead . . .	180	0	9	..	..	..	..	..	..	28·20	37·78	26·83
Caterham	715	0	10	..	..	..	..	..	23·66	28·47	39·52	..
At the Foot of the Northern Slope.												
Croydon (Dr. Westall)	152	1	8	31·41	32·38	24·16	24·58	25·04	22·27	24·54	35·27	25·71

Second Part.	Average Depth of Rain for the Years given above.	Number of Years.	Divisor for Average of same.	Long-Period Average.	Ratio of ditto to that of Croydon.	Ditto to ditto.	Adopted Ratio.
	Ins.			Ins.			
The Denbies . . .	36·54	3	1·038	35·19	1·361	1·384	1·372
Brookmead . . .	30·93	3	1·038	29·80	1·153	1·172	1·162
Caterham	30·55	3	0·972	31·43	1·216	1·236	1·226
Croydon (Dr. Westall)	27·24	9	1·054	25·84	1·000	..	..
Croydon, Tanfield Lodge	Mean 1860–9. Ins. 26·333	10	1·036	25·41	..	1·00	..

NOTE. The divisor in column 3 expresses the ratio of the average depth of rain at Greenwich for the same groups of years in each case as those given in the table, to the average for the period 1815–1873. The short-period averages given have been reduced by it to long-period averages in the same ratio as Greenwich, and the long-period averages of the stations on the escarpment compared with that at Croydon, at the foot of the Northern Slope.

TABLE 2.—SPRINGS BREAKING from THE CHALK WATER SYSTEM.

Names of Springs.	From the Foot of the Chalk Escarpment.		
	Approximate Height above O. D.	Thrown out by	Tributary to
	Feet.		
West of Darent.			
Sepham	206	..	Darent.
Twitton	240	..	,,
Brockham Lime Works	300	Chalk Marl.	Mole.
West of Mole.			
Sherbourn Ponds	..	,,	Wey.
Farnham.			
Bourne Mill Stream	..	,,	,,

Names of Springs.	From the Edge of the System on the North.			
	Height above O. D.		Thrown out by	Tributary to
	Ft.	Ins.		
Orpington	160	0 (abt.)	..	R. Cray.
West Wickham Bourne	..		Thanet Sand.	Ravensbourne.
Croydon	136	0 ,,	,,	Wandle.
Beddington	110	0	,,	,,
Wallington	100	0	,,	,,
Carshalton Park	118	4	,,	,,
,, House	121	9	,,	,,
Cheam (Lower)	..		,,	Beverley.
Ewell	108	0 ,,	,,	Hog's Mill River.
Epsom, Bourne	153	0	,,	,,
West of Mole.				
Little Bookham, Bourne	190	0 ,,	Reading Beds.	R. Mole.
Clandon Park	214	0	,,	R. Wey.
West of Wey.				
Wanborough	..		,,	,,
Poyle Park	..		,,	..

TABLE 3.—CHILGROVE WELL.[1] DEPTH of WATER.

Year.	1836.		1837.		1838.		1839.		1840.	1841.
Months.	Date.	Feet.	Date.	Feet.	Date.	Feet.	Date.	Feet.	Feet.	Feet.
January .	..	..	20	70	3	1·5	5	70	48	36
„ .	..	..	31	90	30	7	..	..	..	..
February .	10	43	17	108	22	9	5	79	105	56
March . .	22	80	23	96	9	34·5	7	73	63	67
April . .	8	101	22	50	9	36	..	..	43	50
May . .	6	83	31	31	18	26	1	48	..	42
„ . .	..	..	..	..	25	23	..	..	..	..
June . .	19	43	30	23	11	21	..	37	23	35
July . .	7	34·5	..	..	13	14	..	28	15	30
August . .	10	21	1	18	..	..	..	20	7	..
September .	..	..	15	7	4	8	..	15	4	..
October . .	3	8·5	16	4·5	1	4	..	52	3	..
„ .	..	..	..	..	8	2·5	..	..	..	..
November .	19	38	1	3·5	3	1·5	..	81	1	..
„ .	..	..	..	..	24	8	..	..	..	..
December .	..	..	2	0·5	1	49	..	95	37	Almost over-flowing
„ .	16	85	..	..	3	70	..	..	..	..
„ .	..	..	..	..	13	84	..	..	..	..

Year.	1842.		1843.		1844.		1845.	1846.	1847.	1848.	1849.	1850.
Months.	Date.	Feet.	Date.	Feet.	Date.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
January .	..	..	..	..	5	47	12	43	33	6	90	54
February .	..	..	1	62	1	74	25	116	38	36	89	40
„ .	..	..	..	..	21	59	..	..	..	..	..	..
March . .	..	..	25	55·5	..	..	32	88	73	87	66	59
April . .	..	..	..	..	1	85·5	31	65	58	102	57	46
May . .	..	..	12	48·5	6	51	31	56	30	84	44	52
June . .	..	..	1	70	3	34	26	36	24	..	44	45
„ . .	..	..	9	83	24	29	..	..	..	..	..	..
„ . .	..	..	23	85	..	..	..	..	..	..	..	..
July . .	18	20	19	58	1	28	22	28	18	37	39	35
August . .	..	..	3	46	9	15·5	17	19	11	26	28	28
September .	2	9·5	12	25	11	8	12	13	7	43	18	20
October .	25	3·2	3	21·3	3	4·5	8	9	3	41	12	17
November .	25	3·3	14	14	1	3·5	6	21	Dry	62	12	12
„ .	..	..	..	..	12	0·7	..	..	..	..	..	..
December .	20	43	7	50	1	8	19	32	Dry	62	12	24
„ .	..	..	..	..	31	12	..	..	..	..	..	..

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[1] Well 135 feet deep.

TABLE 3 (*continued*).—CHILGROVE WELL.[1]

Year.	1851.		1852.		1853.		1854.		1855.	
Months.	Date.	Feet.	Date.	Feet.	Date	Feet.	Date.	Feet.	Date.	Feet.
January .	..	48	..	..	6	135	1	54	..	Dry at 135
,, .	..	..	..	..	..	..	31	65	..	,,
February .	..	..	17	Water for about a fortnight	..	..	..	..	1	..
,, .	..	..	..	..	..	..	28	60	21	7
March . .	..	..	..	..	12	80	..	..	..	..
,, . .	..	..	..	..	31	60	31	48	31	11
April . .	..	..	..	..	..	..	..	..	18	14
,, . .	..	..	..	..	30	50	30	38	30	15
May . .	..	..	..	..	..	..	..	..	7	17
,, . .	..	..	..	..	31	52	31	20	31	18
June . .	..	..	..	..	30	43	30	24	30	18
July . .	..	..	..	..	31	40	31	17·5	31	15·5
August .	..	..	..	..	31	40	31	15·5	31	13
September.	..	..	..	..	..	..	16	14	..	..
,, .	..	..	..	..	30	49	30	14	..	..
October .	..	..	..	..	..	..	..	..	30	11
,, .	..	..	..	..	31	98	31	13	31	19
November .	17	Very low	5	95	..	..	..	Dry at 135	8	35
,, .	27	Nearly dry	22	128	30	84	..		30	44
December .	17	Dry	2	133	..	..	..		..	..
,, .	..	..	11	Water sinks	31	54	..	,,	31	39

	1856.		1857.		1858.		1859.		1860.	
January .	..	..	..	..	..	..	..	..	1	76
,, .	..	..	..	..	..	..	..	..	6	94
,, .	..	..	..	..	..	..	..	..	20	96
,, .	31	76	31	71	31	38	31	11	30	107
February .	..	..	..	..	..	..	2	12	..	..
,, .	28	75	28	59	28	39	28	36	23	91
March . .	..	..	..	..	..	..	..	..	3	80
,, . .	31	56	31	51	31	40	..	..	31	60
April . .	30	54	30	47	30	40	..	..	30	53
May . .	31	44	31	40	31	35	1	35	31	50
June . .	..	..	..	..	..	..	..	..	23	82
,, . .	30	41	30	32	30	31	30	36	30	83
July . .	31	39	31	26	31	25	31	25	31	64
August .	31	31	31	21	31	21	31	20	31	65
September.	30	26	30	17	30	17	30	15	30	65
October .	..	..	..	..	..	..	..	..	15	84
,, .	31	30	31	25	31	13	31	14	31	84
November .	..	..	..	..	..	..	8	24	..	..
,, .	..	..	..	..	..	..	15	35	..	..
,, .	30	31	30	33	30	11	30	38	30	85
December .	18	56	..	..	..	..	..	..	18	107
,, .	31	62	31	38	31	9·5	31	76	31	100

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[1] Well 145 feet deep from January 1853.

TABLE 3 (*continued*).—CHILGROVE WELL.

Year.	1861.		1862.		1863.		1864.		1865.	
Months.	Date.	Feet.	Date.	Feet.	Date.	Feet.	Date.	Feet.	Date.	Feet.
January . . .	..	..	1	70	13	85	..	..	20	21
" . . .	31	93	21	57	24	95	31	59	31	32
February . . .	..	..	..	..	..	..	..	..	18	60
" . . .	28	65	28	61	28	81	28	62	28	67
March	..	..	..	..	..	..	10	75	..	..
"	..	..	..	..	..	..	14	86	..	..
"	..	..	25	69	..	..	22	92	..	..
"	31	66	31	96	31	59	31	90	31	69
April	..	..	..	..	..	..	..	..	13	60
"	30	66	30	82	30	43	30	59	30	50
May	31	50	31	60	31	33	31	46	31	38
June	30	37	30	48	30	30	30	35	30	31
July	31	29	31	38	31	27	31	30	31	25
August	31	24	31	31	31	23	15	25	15	25
September . . .	..	..	..	..	..	..	7	18	1	20
" . . .	30	21	30	25	30	19	30	16	..	..
October . . .	..	..	..	..	..	..	..	..	1	19
" . . .	31	18	31	30	31	23	31	14	29	24
November . . .	20	25	15	36	..	..	..	..	2	66
" . . .	30	40	30	42	30	37	30	12	30	105
December . . .	..	..	15	46	11	58	..	..	14	111
" . . .	31	70	31	65	31	59	31	16	31	91

Year.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.	1876.
Months.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
January .	91	..	..	..	..	46	32	138	22	92	64
" .	141	66	28	112	..	..	..	..	..	..	..
February .	139	88	71	111	..	..	136	..	30	93	54
March . .	107	80	56	113	..	..	101	..	45	114	79
April . .	67	86	51	80	..	..	..	..	50	92	98
May . .	53	84	48	61	..	..	..	..	..	65	70
June . .	40	40	37	51	35	49	..	..	..	42	56
July . .	30	36	29	39	31	40	40	..	..	36	47
August . .	24	31	23	..	30	..	..	23	..	29	38
September .	23	26	17	..	16	..	..	..	..	26	31
October .	29	24	16	24	..	39	23	16	14	23	22
November .	31	24	13	..	..	..	73	..	..	23	21
December .	59	25	15	..	..	..	108	22	92	93	..

All measurements after December 1865 taken on the 1st of each month.

NOTES by the late Mr. LEYLAND WOODS on the CHILGROVE WELL.

From the Rev. J. C. CLUTTERBUCK.

1836. From February 1st to April 11th, 10 weeks, rain about 10 inches. The water in the well rose 58 feet, from 43 to 101 feet.

From November 19th to December 16th, 27 days, rain since November 1st nearly 8½ inches, and in October at least 4½ inches. Water in the well rose 47 feet, from 38 to 85 feet.

1836–1837. From October 3rd to February 20th, 20 weeks, rain 23 inches. Water rose nearly 100 feet, from 8½ to 108 feet, between October 3rd and February 17th.

1837. From February 20th to December 1837 there fell at least 15·30 inches of rain, yet the water in the well gradually diminished from 108 feet on February 17th to ½ foot.

1837–1838. From December to beginning of April, 4 months, rain 8¼ inches. Water in the well rose from ½ foot to 36 feet.

1838. From October 28th to December 13th, 7 weeks, rain 9 inches. Water in the well rose 82½ feet, from 1½ foot on November 3 to 84 feet. In the last 12 days of this period (from December 1st to 13th) it rose 35 feet. From February 22nd to March 9th, 15 days, the water rose 25½ feet with 3·18 inches of rain.

1851. No rain in the month of September. Water in the well and ponds very low.

November 17th. Water is very scarce and springs very low.

„ 27th. The well nearly dry, obliged to draw water for cattle, for the tanks are dry.

1852. February 17th. Water rises in the well; there has been water about a fortnight.

June. Scarcely water enough in the Lavant to wash the sheep.

November 22nd. The water in the well within 7 feet of the top, or 128 feet depth of water.

December 2nd. The water in the well is now 2 feet from the top, or a depth of 133 feet of water.

December 11th. The water sinks, and continued to sink all the month.

TABLE 4.—CHILGROVE WELL REGISTER, SHOWING ANNUAL MEAN DEPTH of WATER, RAIN, and ABSORPTION (calculated).

1 Year.	2 Mean Depth of Water.	3 Ratio of Mean of each Year to Mean of 1853–1860.	4 Rain at Chilgrove.	5 Ratio of each Year to Mean of 1853–1860.	6 Rain at Hemel Hempsted.	7 Ratio to Mean of 1853–1860.	8 Registered Depth of Rain absorbed at Hemel Hempsted.	9 Ratio to Mean of 1853–1860.	10 Ratio of Part absorbed to Total Rain at Hemel Hempsted.	11 Calculated Depth of Rain absorbed at Chilgrove.	12 Ratio to Mean of 1853–1860.	13 Mean Daily Absorption at Chilgrove.	14 Ratio of Mean Daily Absorption of each Year to Mean of Period 1853–1860 (=·01803).
	Feet.		Inches.		Inches.		Inches.			Inches.		Inch.	
1853	65 +	1·6	38·12	1·19	28·46	1·06	3·33	0·59	0·117	4·4	[0·677]	0·012	[0·677]
1854	28 −	0·68	21·81	0·68	18·27	0·68	1·40	0·249	0·076	1·6	0·250	0·004	0·250
1855	18 −	0·439	28·96	0·907	25·89	0·96	5·43	0·96	0·209	6·0	0·919	0·016	0·919
1856	47 +	1·14	32·97	1·033	26·63	0·99	7·42	1·32	0·27	9·0	1·35	0·024	1·35
1857	38 −	0·926	31·24	0·979	28·13	1·04	7·46	1·33	0·26	8·1	1·23	0·022	1·25
1858	27 −	0·66	25·86	0·810	20·50	0·76	3·21	0·57	0·15	4·0	0·60	0·010	0·60
1859	31 −	0·75	34·26	1·074	32·62	1·21	4·59	0·818	0·14	4·8	0·72	0·013	0·72
1860	76 +	1·85	42·00	1·316	34·22	1·27	12·11	2·15	0·353	14·8	2·25	0·040	2·25
Mean of period	41	..	31·9	..	26·84	..	5·61	..	..	6·58	..	0·01803	..

TABLE 5, PART 1.—CHILGROVE WELL REGISTER. TABLE of RISES FROM EXTREME MINIMUM to EXTREME MAXIMUM POSITIONS. 1853–1860.

1 At Minimum.	2 Date.	3 At Maximum.	4 Date.	5 Amount of Rise.	6 Number of Days.	7 Average Rates per Day. Rise.	8 Rain.	9 Ratio of Average Rise to Average Rain.	10 Total Rain at Chilgrove.	11 Rain at Hemel Hempsted.
Feet.		Feet.		Feet.		Inches.	Inch.		Inches.	Inches.
40	July 31, 1853	98	Oct. 31, 1853	58	92	7·5	·141	53·1	13·04	8·30
(5)	Dec. 31, 1854	76	Jan. 31, 1856	(71)	396	2·15	·0833	25·8	33·01	28·86
26	Sept. 30, 1856	71	„ 31, 1857	45	123	4·30	·0822	53·4	10·12	9·87
17	„ 30, 1857	40	Mar. 31, 1858	23	182	1·5	·0854	17·5	15·56	11·81
9½	Dec. 31, 1858	36	Feb. 28, 1859	26½	59	5·4	·209	25·8	12·33	3·12
14	Oct. 31, 1859	107	Jan. 30, 1860	93	92	12·2	·140	86·4	12·95	9·92
50	May 31, 1860	100	Dec. 31, 1860	50	214	2·8	·132	21·2	28·38	22·16

12 Depth absorbed at Hemel Hempsted.	13 Ratio of part absorbed to Total Rain.	14 Ratio of Rain at Hempsted to ditto at Chilgrove.	15 Calculated Depth of Rain absorbed at Chilgrove.	16 Mean Daily Absorption, or amount absorbed.	17 Ratio of Mean Daily Absorption to Mean Daily Rise.	18 Ratio of Rise to Depth absorbed.	19 Ratio of M.D.A. of each Period to M.D.A. required by Mean Water-line (= ·01803).	20 Ratio of ditto to ditto required by Minimum Water-line (= ·00901).	21 M.D.A. required by each Minimum or Starting Point.	22 Ratio of M.D.A. in each Period to ditto.	23 Mean Depth of Water in Well in each Period.	24 Ratio of ditto to Mean of Period 1853–1860.
Inches.			Inches.	Inch.					Inch.		Feet.	
1·89	·227	·636	2·97	·0322	·0043	234·3	1·79	3·58	..	..	62·0	1·51
7·71	·267	·874	8·7	·0219	·0101	97·93	1·21	2·42	..	..	21·9	0·53
3·40	·344	·975	3·48	·0282	·0065	155·7	1·56	3·12	..	..	44·0	1·07
5·64	·477	·759	7·4	·0406	·0270	37·3	2·25	4·50	..	..	32·8	0·80
0·09	·028	·253	(0·35)	..	..	..	..	..	..	..	..	..
7·45	·75	·766	9·7	·1054	·0086	115·0	5·85	11·70	·011	9·5	58·75	1·43
6·75	·304	·780	8·6	·0401	·0143	69·7	2·22	4·44	..	..	74·5	1·8
Mean .	·342	..	..	·0383	..	..	..	..	..	..	..	..

NOTE.—M.D.A. = Mean Daily Absorption.

TABLE 5, PART 2.—CHILGROVE WELL REGISTER. TABLE of FALLS from EXTREME MAXIMUM to EXTREME MINIMUM POSITIONS ATTAINED by the WATER-LINE.

1 At Maximum.	2 Date.	3 At Minimum.	4 Date.	5 Amount of Fall.	6 No. of Days.	7 Average Rates per Day. Fall.	8 Rain.	9 Ratio of Fall to Rain.
Feet.		Feet.		Feet.		Inches.	Inch.	
135	January 6, 1853	40	July 31, 1853	95	206	5·5	·116	50·0
98	October 31, 1853	(5	December 31, 1854	93	426)	2·0	·056	36·6
76	January 31, 1856	26	September 30, 1856	50	243	2·4	·090	26·7
71	,, 31, 1857	17	,, 30, 1857	54	242	2·6	·070	37·14
40	March 31, 1858	9½	December 31, 1858	30½	275	1·3	·078	17·05
36	June 30, 1859	14	October 31, 1859	22	123	2·0	·108	18·4
107	January 30, 1860	50	May 31, 1860	57	121	5·6	·076	74·2

10 Total Rain at Chilgrove.	11 Rain at Hemel Hempsted.	12 Absorbed at Hemel Hempsted.	13 Ratio of Part absorbed to Total Rain.	14 Ratio of Rain at Hemel Hempsted to ditto at Chilgrove.	15 Calculated Depth of Rain absorbed at Chilgrove.	16 Mean Daily Absorption.	17 Ratio of Mean Daily Absorption to Mean Daily Fall.	18 Ratio of Fall to Depth absorbed.	19 Ratio of M.D.A. of each Period to M.D.A. required by Mean Water-line (= ·01803).
Inches.	Inches.	Inches.			Inches.	Inch.			
22·83	17·83	1·27	·071	·780	1·62	·0070	..	703	·388
24·06	20·60	2·57	·124	·858	3·00	·0070	..	285	·388
21·78	17·39	4·54	·261	·798	5·68	[·0233]	..	105	..
17·04	16·20	4·23	·261	·950	4·44	·0183	..	145	..
21·52	16·12	0·80	·049	·749	1·06	·0038	..	345	·21
13·32	12·98	0·00	..	..	..	..	..	..	..
9·28	8·53	2·41	·282	·919	2·6	[·0214]	..	263	..
Mean . .	..	..	·174	..	..	·0175	..	..	..

TABLE 6.—CHALK AREA BETWEEN the DARENT and the MOLE. SEASONAL VARIATIONS in the HEIGHT of the WATER-LINE.

Name of Well.	Heights above O. D.		Differ-ence.	Dates of Observations.		Calculated Maxima.			Calculated Minima.			Adopted Values for the Period.		
	Observed Maximum.	Observed Minimum.		At observed Maximum.	At observed Minimum.	Multiplier for Difference.	Add to observed Minimum.	Heights above O. D.	Multiplier for Difference.	Subtract from observed Max.	Height above O. D.	Heights above O. D. Max.	Heights above O. D. Min.	Amount of Variation
	Feet Ins.	Feet Ins.	Feet Ins.				Ft. Ins.	Feet Ins.		Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Feet Ins.
Turf Cottage	185 7	169 0	16 7	April 7, 1873	Nov. 12, 1874	1·073	17 9	186 9	..	..	..	187 0	169 0	18 0
Hundred Acres	178 9	169 9	9 0	„ „	„ „	1·073	9 8	179 5	..	..	..	180 0	169 9	10 3
Banstead	238 6	237 0	1 6	„ „	„ „	1·073	1 7	238 7	..	..	..	239 0	237 0	2 0
Sutton Hill	136 11	128 0	8 11	„ 12, „	Dec. 4, 1873	1·078	9 7	137 7	1·51	13 6	123 5	138 0	123 6	14 6
Barrow Hedges Farm	149 4	135 6	13 10	„ „	„ „	1·078	14 10	150 4	1·51	20 10	128 6	150 4	128 6	21 10
Pikeshill	159 1	136 0	23 1	Feb. 28, „	Nov. 18, 1874	1·000	23 1	159 1	1·00	..	..	159 1	136 3	22 10
Fitplace Farm	158 11	137 8	21 3	Mar. 13, „	„ „	1·064	22 8	160 4	..	..	..	160 4	137 8	22 8
Juniper Cottage, No. 1	160 4	141 3	19 1	„ 29, „	„ „	1·050	20 0	161 3	..	..	..	161 3	141 3	20 0
„ „ No. 2	162 5	147 10	14 7	„ „	Dec. 1, 1873	1·050	15 3	163 1	1·51	22 0	140 5	163 0	140 0	23 0
Olive Cottage	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Common Fields	167 7	146 11	20 8	Feb. 28, 1873	Nov. 18, 1874	1·000	20 8	167 7	..	..	..	167 7	146 11	20 8
Amato Inn	158 0	140 0	18 0	Mar. 7, „	„ „	1·073	19 3	159 3	..	..	..	160 0	140 0	20 0
Northlieu Farm	161 1	150 8	10 5	Ap. 24, „	Dec. 6, 1873	1·127	11 8	162 5	1·51	15 8	145 5	162 0	145 0	17 0
Tudor Cottage	(209 0)	181 0	28 0	Early „	Nov. 11, 1874	..	..	(209 0)	..	..	..	210 0	180 0	30 0
Old Stables near Red Deer	(178 0)	156 0	22 0	„ „	„ „	..	..	(178 0)	..	..	..	180 0	156 0	24 0
Grand Stand	167 6?	167 0	0 6	Ap. 12, „	Nov. 18, 1874	..	..	..	..	..	..	..	..	..

		Feet. Ins.			Feet. Ins.
Common Fields Well.—Data used in calculating the maximum in each case at the date of the maximum observed in Common Fields Well	April 7, 1873	(166 2)	Pikeshill Well.—Data used in calculating the minimum for wells previously measured twice, but not measured in November 1874	December 1, 1873	143 10
	„ 12, „	166 1			
	Mar. 13, „	166 4			
	„ 29, „	166 7			
	„ 7, „	166 2			
	April 24, „	165 3			

TABLE 7.—DIFFERENCES in HEIGHTS, and GRADIENTS, on the CHALK WATER SYSTEM, EPSOM.

Date.	Heights above O.D.		Difference.	Distance.	Gradient.		Heights above O.D.		Difference.	Distance.	Gradient.		Heights above O.D.		Difference.	Distance.	Gradient.	
	Common Fields.	Juniper Cottage.			1 in	Per Mile.	Juniper Cottage.	Pitplace Farm.			1 in	Per Mile.	Pitplace Farm.	Pikeshill.			1 in	Per Mile.
	Ft. Ins.	Ft. Ins.	Ins.	Ft.		Feet.	Ft. Ins.	Ft. Ins.	Inches.	Feet.		Feet.	Ft. Ins.	Ft. Ins.	Ins.	Ft.		Feet.
1873 Mar. 11	166 6	..	..	950	..	..	..	..	..	1,000	..	..	158 8	158 7¼	0¾	750	12,000	0·44
„ 12	166 6	162 2	52	..	219	24·1	162 2	158 9	41·0	..	292·6	18·04	158 9	158 8½	0½	..	18,000	0·29
„ 13	166 4¾	162 3¼	49½	..	230	22·9	162 3¼	158 10¼	41·0	..	292·6	18·04	158 10¼	158 7¾	2½	..	3,600	1·46
„ 14	166 1	..	..	..	..	..	..	158 7½	..	..	..	..	158 7½	158 5	2½	..	3,600	1·46
„ 15	166 1¼	161 10¾	50½	..	225	23·47	161 10¾	158 5¼	41·5	..	289·1	18·16	158 5¼	158 4	1¼	..	7,200	0·73
„ 17	166 3½	162 2¾	48¾	..	233	22·6	162 2¾	158 7¼	43·5	..	275·8	19·14	158 7¼	158 5¼	2	..	4,500	1·11
„ 18	..	..	..	..	..	..	..	158 7	..	..	..	..	158 7	158 5½	1½	..	6,000	0·88
„ 19	166 2½	161 11¾	50¾	..	224	23·5	161 11¾	158 7	40·75	..	294·4	17·93	158 7	158 5	2	..	4,500	1·11
The Bourne or Intermittent Spring in Church Street, which had been flowing up till now, ran dry on March 22nd.																		
	..	..	$50\frac{3}{10}$	..	226	23·6	..	..	41·5	..	289·1	..	..	..	1⅝	..	5,538	0·9
Mar. 25	166 7½	162 3½	52	..	219	24·1	162 3½	158 9½	42·0	..	285·7	18·47	158 9½	158 6	3½	..	2,571	2·05
„ 27	166 8¾	162 5¼	51½	..	221	23·8	162 5¼	158 9¾	43·5	..	275·8	19·14	158 9¾	158 7	2¾	..	3,272	1·61
„ 29	166 7½	162 5	50½	..	225	23·47	162 5	158 9¾	43·25	..	277·4	19·02	158 9¾	158 6¼	3½	..	2,571	2·05
Apr. 2	166 4	162 1½	50½	..	225	23·47	162 1½	158 6½	43·0	..	279·0	18·92	158 6½	158 3¾	2¾	..	3,272	1·61
„ 4	166 2¼	162 0¼	50	..	228	23·15	162 0¼	158 5¾	42·5	..	282·2	..	158 5¾	158 3¼	2½	..	3,600	1·46
„ 9	166 2	..	..	..	..	..	..	158 6	..	..	..	..	158 6	158 3½	2½	..	3,600	1·46
„ 11	166 1	161 11½	49½	..	230	22·9	161 11½	158 6	41·5	..	289·1	18·16	158 6	158 2¼	3¾	..	2,400	2·2
„ 14	165 11½	161 7	52½	..	217	24·33	161 7	158 2	41·0	..	292·6	18·04	158 2	157 11	3	..	3,000	1·76
„ 15	166 1½	161 7¾	53¾	..	212	24·9	161 7¾	158 2½	41·35	..	290·9	18·15	158 2½	157 11¾	2¾	..	3,272	1·61
„ 16	(165 9½)	162 0½	(45)	..	(253)	(20·8)	162 0½	158 6¾	41·75	..	287·4	18·37	158 6¾	158 3¼	3½	..	2,571	2·05
Dec. 1	(146 4)	147 10	..	..	..	..	147 10	..	..	..	..	..	..	143 10¾	..	..	..	..
1874 Nov. 18	146 11	(143 0)	..	..	..	..	..	137 8	..	..	..	..	137 8	136 3	17	..	529	10·0

TABLE 8.—CHALK WELLS in SURREY. WEST of the MOLE.

MEASURED by the late ARTHUR BARCLAY, between 1841 and 1845.

	Depths.						Heights above O.D.			
—	September.				March.		Of Well Mouth.	Of Top of Water.		
	Of Water.		Of Well.		Of Water.			September.		March.
	Feet.	Ins.	Feet.	Ins.	Feet.	Ins.	Feet.	Ft.	Ins.	Feet.
Dr. Gordon's Farm . . .	3	0	41	0	5	0	..	..		..
The Duke's Stables . . .	3	6	54	0	8	0	..	..		..
Westhumble Cottage . .	2	2	69	6	5	6	..	..		..
Cottage near	1	6	56	0	5	0	..	..		..
Chapel Farm.	2	0	85	0	12	6	..	..		..
Old Dean.	15	0	119	0	31	0	240	136	0	152
Tanner's Hatch	3	0	205	0	8	4	..	..		..
Phœnix Farm	15	0	307	0	19	0	..	..		..
Polsdon	212	0	507	0	222	0	..	..		..
Bagden	15	6	124	0	19	0	255	146	6	150

CHALK WELLS at WEST HORSLEY MEASURED by the Rev. H. S. DE CERJAT, Rector.

September 18th, 1868.

—	Depth of Water.		Depth of Well.
	Feet.	Ins.	Feet.
Tunmore Farm	4	0	58
„ Cottages	0	3	44
Wix Farm	6	0	51
Lawrence's.	6	0	70
T. Woodham's	6	0	94
J. Woodham's	3	0	101

TABLE 9.—CHALK WELLS in SURREY. WEST of the WEY.

MEASURED by J. LUCAS.

The "Height of the Well Mouth," and consequently the "Height of the Water-line," above O.D., are approximate. Inches have been omitted in estimating the water-line.

—	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	Remarks.
	Feet.	Ft.	Ins.	1876	Ft.	Ins.	Feet.	
Farnham Parish.								
Farm south of Badshotlea	280	48	2	Dec. 1	43	8	236	
Smithy near Six Bells.	262	28	6	„ 1	27	2	235	
„ „ „	262	28	6	„ 9	24	1	..	
Halfway House. . .	400	124	6	„ 1	117	4	283	
Dippenhall	..	105	0	..	99	0	..	Goes to Upper Greensand.
Seale Parish.								
Whitelane Farm . .	390	..		Nov. 30	..		..	To stage, dry, 97 feet.
Whiteways End Stables	305	82	0	Dec. 9	75	4	230	
Wanborough Parish.								
New House. . . . East Flexford . . .	336	[48]	0	Nov. 30	[40]	0	296	To stage, dry, 37 feet 4 inches.
Inwood	390	99	0	„ 30	97	6	292	
Compton Parish.								
Down Place in Park .	315	75	0	Nov. 30	61	6	283	
St. Nicholas Parish.								
Wilderness	304	73	4	Nov. 30	65	0	239	To stage, 52 feet; water sometimes rises above ditto.
Manor Farm Cottage .	295	43	0	„ 30	40	2	255	

TABLE 10.—CHALK WELLS in SURREY. WEST of the MOLE.

MEASURED by J. LUCAS.

—	Height of Well Mouth.	Depth of Well.		Dates.		Depth to Water.		Height of Water-line.	Altitude of Point of Observation.	Temperature. Degrees Fahr.
	Feet.	Feet.	Ins.	1876		Feet.	Ins.	Feet.	Feet.	°
Guildford Parish.										
Warren Farm . .	320	149	6	Oct.	7	120	6	200	172	51·0
Watford Farm . .	193	78	8	„	9	76	8	116	..	..
Vale Cottages . .	198	80	4	„	9	75	5	122	119	51·0
Pit Farm . . .	210	92	4	„	9	83	6	126	..	..
Pareora	300	167	8	„	9	164	4	135	..	..
Merrow Parish.										
Levelsgrove . . .	..	[90]	0	Oct.	7	(To staging, dry, 60 ft.)			..	..
Cottage, do. . . .	270	89	4	„	7	84	0	186	..	..
Lodge, do. . . .	255	72	10	„	7	70	8	184	..	..
Merrow Village.										
Sheeplane Cottages.	265	77	8	Oct.	7	73	2	192	..	..
Post Office . . .	267	79	4	„	7	75	0	192	..	..
Swayne's. . . .	..	95	3	„	7	[91]	0	..	..	..
Merrow House . .	..	[75]	0	„	7	..		..	..	..
Young's Cottage .	261	75	8	„	7	69	8	191	..	..
Rose Cottages . .	255	69	8	„	7	63	8	191	..	..
Downs Lane . .	282	84	6	„	7	82	1	200	..	..
„ „ in field.	302	113	4	„	7	101	9	200	..	..
Well at Inn . . .	275	90	5	..		86	1	189	..	..
Hall Place . . .	263	77	11	..		71	8	191	..	..
W. Clandon Parish: Clandon Village.										
West Clandon Place	250	(Shaft.) 135	0	Nov.	2	50	0	200	116	52·0[1]
Tanfield House . .	270	(Shaft.) [70]	0	„	2	56	4	214	206	50·5[1]
Post Office . . .	300	82	4	„	2	80	0	220	219	50·0
Drewitt's . . .	295	76	4	Oct.	9	74	8	220	..	..
„ . . .	295	76	4	Nov.	2	74	10	220	..	..
E. Clandon Parish.										
Grotto Clump . .	284	68	8	Sep.	29	62	0	222	..	..
Rectory	288	74	2	„	29	67	4	221	..	..
Cottage	298	77	2	„	29	76	4	221	..	..
Opposite church, 1 .	295	77	4	„	29	73	4	221	..	..
„ „ 2 .	..	75	2	„	29	Dry.		..	..	..
Cottage	300	85	7	„	29	78	8	221	..	..
P.H. in yard . .	297	81	8	„	29	76	1	221	..	..
Manor Farm Cottage	297	82	8	„	29	76	4	220	..	..
„ „ House .	300	90	0	„	29	78	0	222	..	..
Old cottages. . .	302	88	8	„	29	80	0	222	..	..
Albury Parish.										
Well House Farm .	420	129	0	Oct.	9	127	6	292	..	..
„ „ .	420	..		Nov.	2	(Dry at 127 ft. 7 ins.)			..	..
Newlands House .	528	262	2	Oct.	9	251	5	277	..	..
Scotland Farm . .	518	194	0	Nov.	2	185	10	332	325	50·0
Shiere Parish.										
Colekitchen Farm .	397	125	0	Nov.	2	118	0	279	273	50·0

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[1] Bored to a greater depth.

Table 10 (*continued*).—Chalk Wells in Surrey. West of the Mole.

—	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	Altitude of Point of Observation.	Temperature. Degrees Fahr.
	Feet.	Feet.	Ins.	1876	Feet.	Ins.	Feet.	Feet.	°
West Horsley Parish.									
House near West Horsley Church .	286	94	2	Sep. 27	86	2	200	..	..
West Horsley Place (new well) . .	275	94	8	„ 27	77	9	197	..	..
West Horsley Rectory	..	110	0	„ 27	..		..	..	..
Hatchlands, East Lodge	315	101	0	„ 29	92	5	222	..	..
Tunmore Farm . .	260	60	0	„ 26	51	0	209	..	..
„ Cottage .	252	44	8	„ 26	41	8	210	..	..
Wix Farm (pump, covered) . . .	..	..		„ 26	..		..	..	..
T. Woodham's . .	295	95	5	„ 26	83	6	211	..	..
J. Woodham's . .	314	102	0	„ 26	97	0	217	..	..
R. Woodham's . .	275	73	8	„ 26	64	7	211	..	..
Old well in field .	289	76	0	„ 26	74	9	214	..	..
Tenement . . .	270	70	2	„ 26	64	8	205	..	..
Chalk pit . . .	300	84	1	„ 26	77	3	223	..	..
East Horsley Parish.									
Cracknorth Lodge .	306	106	0	Sep. 9	97	4	209	..	..
„ „ .	306	106	0	Nov. 14	97	4	209	..	..
Green Dene Cottage	450	250	0	„ 14	222	6	228	..	..
Old „ „ „	395	176	4	„ 14	173	0	223	..	..
Robarns	325	101	8	Sep. 27	96	9	228	..	..
„	325	101	8	Nov. 14	97	4	228	..	..
Manor Farm . .	300	116	0	Sep. 27	..		..	..	..
„ House . .	300	116	8	„ 27	110	6	189	..	..
„ „ Orchard	298	110	0	„ 27	108	7	189	..	..
Garden next churchyard	301	117	5	„ 27	111	7	189	..	..
Effingham Parish.									
Effingham Hill Lodge (goes to Upper Greensand) . .	635	[399]	0	Sep. 28	287	3	348	..	..
„ „ Park	557	192	0	„ 6	171	10	385	..	..
„ „ „	557	192	0	„ 28	173	6	383	..	..
„ „ House	..	189	4	„ 6	171	0	..	..	50·0
„ „ Laundry Farm (goes to Upper Greensand)	450	[379]	0	„ 6	246	6	203	135	48·2
„ „ „	450	[379]	0	„ 28	249	0	201	..	..
Warren Farm . .	350	146	4	„ 9	127	4	223	..	..
Moore's	280	123	4	„ 9	109	4	171	..	..
Well in orchard. .	269	113	4	„ 9	102	0	167	..	..
Westmore (A) . .	236	95	8	„ 9	77	0	159	..	..
„ (A) . .	236	95	8	Nov. 14	85	9	150	..	..
„ The Plough (B) . .	230	89	0	Sep. 9	72	5	158	..	..
„ House (C).	234	103	0	„ 9	75	5	159	..	..
„ Cottage (D)	226	84	0	„ 9	67	4	159	..	..

TABLE 10 (*continued*).—CHALK WELLS in SURREY. WEST of the MOLE.

—	Height of Well Mouth	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	Dates.	Depth to Water.		Height of Water-line.	Altitude of Point of Observation.	Temperatures, Degrees Fahr.	
	Feet.	Ft.	Ins.	1874	Ft.	Ins.	Feet.	1876	Ft.	Ins.	Feet.	Feet.	1874 °	1876 °
Effingham Parish (continued).														
Lower Farm[1] . .	160	150	0	..	..		..	Sep. 9	45	5	115	11	..	52·2
Orestan Farm . .	228	80	0	..	..		..	„ 9	67	0	161	149	..	50·0
„ „ . .	228	80	0	..	..		..	Nov. 14	73	4	155	..	..	..
Keeper's House in Old Quarry . .	260	84	8	..	..		..	Sep. 9	81	1	179	..	..	..
„ „ . .	260	84	8	..	..		..	Nov. 14	81	4	179	..	..	..
Cottage by highroad	330	139	4	..	..		..	Sep. 9	127	3	203	..	..	..
„ „	330	139	4	..	..		..	Nov. 14	130	0	200	..	..	..
Little Bookham Parish.														
Hogden	470	153	0	Nov. 19	150	0	320	Sep. 6	149	4	320	318	49·0	49·5
Ranmore Farm . .	550	254	0	..	..		..	„ 28	191	0	359	..	..	..
Preston House . .	(To stage, dry, 56 ft. 3 ins.)			..	..		..	„ 9	..		..	..	..	..
Great Bookham Parish.														
Bagden[1]	255	124	0	Nov. 19	114	0	141	Sep. 6	105	7	149	..	50·5	..
Tanner's Hatch[2] .	375	206	7	..	..		..	„ 6	192	11	182	170	..	50·
Yewtree Farm . .	450	224	0	Nov. 19	224	0	226	„ 6	189	9	260	227	49·3	..
Roaring House Farm	286	162	6	..	..		..	„ 7	148	3	138	125	..	51·
Ralph's Cross, Upper	258	115	7	..	..		..	„ 7	102	1	156	..	..	..
„ „ „	258	115	7	..	..		..	„ 25	104	9	153	..	..	..
„ „ Lower	247	115	9	..	..		..	„ 25	94	10	152	..	..	..
Eastwick, opposite National School .	224	98	4	..	..		..	„ 7	81	2	143	127	..	51·
Eastwick, next to National School .	218	95	4	..	..		..	„ 7	75	10	142	124	..	51·
Eastwick Public Well	217	98	4	..	..		..	„ 7	75	10	141	120	..	51·
„ Ivy House	219	97	0	..	..		..	„ 7	78	2	141	..	..	..
„ Poulter's .	212	87	0	..	..		..	„ 7	71	7	140	126	..	51·
„ The Anchor	216	95	2	..	..		..	„ 7	75	2	141	122	..	51·
„ Cottage .	215	88	2	..	..		..	„ 7	74	9	140	128	..	51
„ Park . .	212	108	4	..	..		..	„ 7	73	9	138	..	..	..
Chitty's	213	73	10	..	..		..	„ 7	63	9	149	..	..	..
Firfield House . .	214	79	10	..	..		..	„ 7	64	4	149	..	..	..
Crown Inn . . .	214	79	2	..	..		..	„ 7	62	4	151	..	..	..
Wood, Butcher . .	210	72	8	..	..		..	„ 7	59	4	150	..	..	..
Horley and Barclay Cottages . . .	206	85	10	..	..		..	„ 7	56	6	149	121	..	51
High Street, opposite Crown	215	79	8	..	..		..	„ 7	63	6	151	..	..	..
Grantham's . . .	220	89	7	..	..		..	„ 7	68	0	152	132	..	51
Dawnay's Cottages .	233	92	6	..	..		..	„ 7	78	4	154	..	..	..
Bookham Grove .	250	201	4	..	..		..	„ 7	94	4	155	50	..	..

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[1] See also Table 8.

[2] Through London Clay to Chalk (?).

TABLE 10 (*continued*).—CHALK WELLS in SURREY. WEST of the MOLE.

—	Height of Well Mouth.	Depth of Well.	Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.	
	Feet.	Ft. Ins.	1874	Ft. Ins.	Feet.	1876	Ft. Ins.	Feet.	Feet.	1874 °	1876 °
Great Bookham Parish (continued).											
Sir Walter Farquhar's Lodge .	270	119 3	..	..	..	Sep. 7	109 0	161	..	..	..
„ „ .	270	119 0	..	..	..	Nov. 14	114 4	156	..	..	..
Polesden Lacy . .	..	507 0	(325 feet of line did not reach water)			Sep. 25	..	..	..	..	..
The Grange. . .	226	89 8	..	..	..	„ 7	66 10	159	..	..	..
Cottage east of do. .	215	73 6	..	..	..	„ 7	57 3	158	..	..	..
„ „ .	215	73 6	..	..	..	Nov. 14	64 8	150	..	..	..
Elm Cottage. . .	..	66 8	..	..	..	Sep. 9	52 11	..	..	..	..
Bugs Farm . . .	193	56 0	..	..	..	„ 9	35 0	158	138	..	51·6
Beershop. . . .	197	59 4	..	..	..	„ 9	38 10	158	139	..	51·6
Preston Cross . .	215	75 1	..	..	..	„ 9	54 8	160	141	..	51·6
Dorking Parish.											
Denbies	600	444 0	..	..	..	Sep. 29	424 10	175	..	..	..
Bradley Farm . .	182	..	..	..	..	„ 29	(To stage, dry, 60 ft.)		..	..	..
Bradley Lane Cottages	172	45 8	..	..	..	„ 29	Dry.	..	..	..	..
Mickleham Parish.											
Cottage at Westhumble . . .	145	42 0	Nov. 14	38 0	107	..	..	..	..	..	..
Westhumble. . .	165	60 0	„ 19	51 9	113	Sep. 6	52 8	112	..	50·5	..
Chapel Farm . .	..	..	..	..	..	„ 6	(To stage, dry, 70 ft. 7 ins.)		..	..	..
Old Dean . . .	240	120 0	Nov. 19	109 6	130	„ 6	101 8	138	..	..	..
Norbury Park . .	410	[340] 0	..	..	..	..	..	..	..	..	..
Fetcham Parish.											
Fetcham Park Stables	..	..	..	..	..	Sep. 7	(To stage, dry, 36 ft.)		..	..	..
Leatherhead Parish.											
Bockett's Farm . .	190	80 0	..	..	..	Sep. 7	75 9	114	111	..	51·3

TABLE 11.—CHALK WELLS in SURREY.

——	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.
	Feet.	Feet.	Ins.	1873	Feet.	Ins.	Feet.
Ashtead Parish.							
Ashtead	248	120	0	..	..		..
Headley Parish.							
High Ashurst (goes to Upper Greensand ?)	490	397	0	..	..		..
The Rectory, Headley . .	570	..		..	..		..
Epsom Parish.							
Pikeshill	178	42	4	Feb. 28	19	1	159
„	„	„		Dec. 1	34	3	144
Pitplace Farm	191	60	4	Mar. 13	32	2	159
„ „	„	„		Dec. 1	47	4	143
Juniper Cottage, No. 1 . .	203	67	9	Mar. 29	43	4	160
„ „ „ 1 . .	„	„		Dec. 1	57	6	146
„ „ „ 2 . .	210	70	4	Mar. 27	48	5	162
„ „ „ 2 . .	„	„		Dec. 1	63	0	147
Olive Cottage	..	78	0	Mar. 29	50	1	..
„ „	..	..		Dec. 1	65	0	..
Common Fields Well . . .	219	75	0	Feb. 28	52	0	167
Amato Inn	190	58	8	Mar. 7	31	11	158
Langley Bottom	275	121	4	..	..		..
The Warren	450	[370]	0	..	..		..
Sherwood's	424	260	0	..	..		..
Grand Stand	430	..		April 12	262	6	167
Ewell Parish.							
Priest's Hill Farm . . .	219	81	2	Dec. 6	70	3	148
Longdown Cottage . . .	230	124	0	Mar. 14	78	10	151
„ „ . . .	„	„		April 24	79	6	151
Northlieu Farm	250	110	2	„ 24	88	10	161
„ „ „	„	„		Dec. 6	99	4	150
Cuddington Parish.							
Manor Farm, Cuddington .	190	78	2	Dec. 6	68	6	121
Well at Cottages near . .	190	60	0	„ 6	55	0	135
Walnut-tree Farm	315	..		„ 6	157	0	158
Cheam Parish.							
The Folly	..	133	0	..	..		..
Cheam	190	74	0	..	..		..
Nonsuch Place	170	50	4	..	..		..
Sutton Parish.							
Sutton, near the Cock . .	200	80	0	April 12	64	0	136
Sutton Lodge Farm . . .	260	..		„ 7	79	0	181
Turf Cottage	340	174	0	„ 7	154	5	185
Sutton Hall	178	55	8	..	..		..

East of the Mole. Measured by J. Lucas.

Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.	
1874	Ft. Ins.	Feet.	1875	Ft. Ins.	Feet.	1876	Ft. Ins.	Feet.	Feet.	1874 °	1876 °
Nov. 18	114 0	134	June 5	110 0	138	..	..	..	119	51·0	..
„ 14	231 6	258	..	..	..	..	..	..	..	49·5	..
„ 14	287 0	283	June 5	285 0	285	..	..	..	..	..	..
Nov. 18	42 0	136	May 31	29 8	148	Oct. 24	40 7	137	..	51·0	..
..	..	..	..	..	..	..	..	..	..	..	..
Nov. 18	53 4	137	May 31	44 4	146	Oct. 24	53 3	137	..	50·5	..
..	..	..	..	..	..	..	..	..	..	..	..
Nov. 18	62 5	141	May 31	55 9	148	Oct. 24	63 0	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	May 31	61 10	149	Oct. 24	68 0	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	May 31	62 0	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
Nov. 18	72 0	147	May 31	65 6	154	..	..	..	..	..	..
„ 18	49 9	140	„ 31	42 10	147	Nov. 13	48 0	141	..	..	..
..	..	..	..	..	..	„ 13	121 0	154	..	..	..
..	..	..	..	..	..	„ 13	254 4	195	..	..	..
..	..	..	..	..	..	„ 13	243 10	180	..	..	..
Nov. 18	263 0	167	May 31	298[1] 0	132[1]	„ 13	262 0	168	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	Oct. 24	101 4	129	107	..	50·5
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
Nov. 12	127 0	..	May 31	123 0	..	..	..	..	..	50·5	..
..	..	..	..	..	..	Oct. 24	66 10	123	..	..	..
..	..	..	..	..	..	„ 24	48 2	122	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	May 31	To staging, dry, 107 ft.		..	..	..	..	..	..
										1875	
Nov. 12	171 0	169	„ 31	164 0	175	..	..	..	..	50·0	..
..	..	..	..	..	..	Oct. 24	54 0	124	124	..	51·0

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[1] After the Derby Week.

TABLE 11 (*continued*).—CHALK WELLS in SURREY.

—	Height of Well Mouth.		Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	
	Feet.	Ins.	Feet.	Ins.	1873	Feet.	Ins.	Feet.	Ins.
Banstead Parish.									
Hundred Acres	417	9	263	0	April 7	239	0	178	9
Warren Farm	350	0	191	0	Dec. 6	189	2	161	0
Banstead P. W.	521	0	330	0?	April 7	282	6	238	0
Apsley Cottage	..		..		..	..		..	
Cannon Farm. Old well, covered	552	0	..		..	..		..	
Tadworth Court	560	0	283	10	..	..		..	
Banstead Newton	590	0	263	0	..	..		..	
Chipstead Parish.									
Well House	435	0	166	0	..	..		..	
Wellfield Shaw	..		160	0	..	..		..	
Pigeon House Farm . . .	390	0	127	0	..	..		..	
School Farm	..		125	0	..	..		..	
Rumbold's Castle	345	0	120	0	..	..		..	
Cottage south of Denehouse .	334	0	108	6	..	..		..	
Hooley Cottage	360	0	130	0	Dec. 3	91	0	269	0
„ „	360	0	130	0	..	..		..	
Star Inn	..		118	6	..	..		..	
Merstham Parish.									
Jolliffe Arms[1]	378	0	100	0	..	..		..	
„ „	..		..		..	..		..	
Harpsoak	447	0	180	0	..	..		..	
„	..		..		..	..		..	
Dean Farm	425	0	182	0	..	..		..	
„ „	..		..		..	..		..	
Coulsdon Parish.									
Tudor Cottages	215	0	36	5	Dec. 3	30	0	185	0
„ „	„		„		..	..		..	
Flint Cottage	230	0	43	4	Dec. 3	35	0	195	0
„ „	„		„		..	..		..	
„ „	„		„		..	..		..	
Stoatsnest	240	0	51	0	Dec. 3	43	0	198	0
Hope Cottage	245	0	49	0	„ 3	43	4	201	0
„ „	245	0	49	0	„ 3	..		..	
Red Lion	250	0	53	0	„ 3	47	2	203	0
„ „	„		„		..	..		..	
„ „	„		„		..	..		..	
Marlpit Lane	285	0	77	6	Dec. 3	66	7	218	0
„ „	285	0	77	6	..	..		..	
Woodmansterne Parish.									
Oaks Park	360	0	221	0	April 7	197	0	163	0
Woodmansterne, P. W. . .	460	0	279	0	Dec. 4	278	0	182	0
Stagbury	330	0	108	0	..	..		..	
Farm near Woodmansterne Rectory	410	0	245	0	..	..		..	
Woodmansterne Rectory . .	380	0	221	0	..	..		..	
Shepherd's Cottage . . .	..		81	4	..	..		..	

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[1] Through Chalk Marl to Upper Greensand.

East of the Mole. Measured by J. Lucas.

Dates.	Depth to Water.		Height of Water-line.	Dates.	Depth to Water.		Height of Water-line.	Dates.	Depth to Water.		Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.	
1874	Ft.	Ins.	Feet.	1875	Ft.	Ins.	Feet.	1876	Ft.	Ins.	Feet.	Feet.	1874 °	1876 °
Nov. 12	248	0	169	May 31	243	0	174	..	..		..	..	..	..
..	..		..	„ 31	183	0	167	..	..		..	..	..	..
Nov. 12	284	0	237	„ 31	285	0	236	Aug. 19	286	4	234	..	50·5	..
„ 12	279	0	..	„ 31	265	0	..	„ 19	278	8	..	..	1875 50·5	51·0
..	..		..	..	..		..	„ 19	..		..	..	..	..
..	..		..	..	..		..	„ 19	262	4	298	..	..	..
..	..		..	June 5	246	0	344	„ 19	246	4	344	328	..	49·1
Nov. 14	141	0	294	May 25	111	2	324	Feb. 28	108	3	326	..	..	..
„ 14	146	0	..	..	..		..	„ 28	115	8	..	..	..	..
„ 14	113	0	277	May 25	77	3	313	„ 28	74	4	316	..	..	..
..	..		..	„ 25	86	0	..	„ 28	82	0	..	..	..	..
Nov. 12	107	0	238	„ 25	77	11	267	„ 28	74	0	270	..	..	..
„ 12	96	0	238	„ 25	70	0	264	„ 28	66	8	267	..	..	..
..	..		..	„ 25	65	0	295	„ 28	54	0	306	..	1875 49·5	..
..	..		..	..	..		..	Dec. 6	96	10	263	..	..	..
..	..		..	..	..		..	„ 6	99	4	..	..	..	..
..	..		..	May 25	60	5	317	Feb. 28	58	4	319	..	1875 50·5	50·0
..	..		..	..	..		..	Dec. 6	82	2	296	..	..	..
..	..		..	..	..		..	Feb. 28	127	4	320	..	..	..
..	..		..	..	..		..	Dec. 6	156	5	290	..	..	..
..	..		..	May 25	120	2	305	Feb. 28	115	6	309	..	50·5	..
..	..		..	..	..		..	Dec. 6	149	4	275	..	..	..
Nov. 11	34	0	181	May 25	21	0	194	Jan. 28	21	0	194	..	..	..
..	..		..	..	..		..	Apr. 28	16	7	199	..	..	..
..	..		..	May 25	28	0	201	Jan. 28	28	1	202	..	..	..
..	..		..	..	..		..	Feb. 28	27	9	202	..	..	..
..	..		..	..	..		..	Dec. 6	36	0	194	..	..	..
..	..		..	..	..		..	..	..		..	..	..	..
..	..		..	..	..		..	Jan. 28	37	5	208	..	..	..
..	..		..	..	..		..	Dec. 6	47	0	198	..	..	..
..	..		..	May 25	40	10	209	Jan. 28	36	4	214	..	..	..
..	..		..	..	..		..	Feb. 28	39	4	210	..	..	..
..	..		..	..	..		..	Dec. 6	49	0	201	..	..	..
..	..		..	May 25	56	0	229	Jan. 28	54	2	231	..	..	..
..	..		..	..	..		..	Dec. 6	69	10	215	..	..	..
..	..		..	..	..		..	Mar. 29	198	0	..	..	..	..
..	..		..	..	..		..	„ 29	267	0	193	..	..	..
Nov. 12	92	0	238	May 25	71	8	258	Feb. 28	69	0	261	..	..	..
..	..		..	..	..		..	Mar. 29	206	6	204	..	..	..
..	..		..	..	..		..	„ 29	175	10	204	..	..	..
..	..		..	May 25	70	0	..	Feb. 28	69	0	..	..	..	..

TABLE 11 (*continued*).—CHALK WELLS in SURREY.

——	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.
	Feet.	Feet.	Ins.	1873	Feet.	Ins.	Feet.
Carshalton Parish.							
Sutton Hill.	200	..		April 12	63	1	136
„ „	200	..		Dec. 4	72	0	128
Barrow Hedges Farm. . .	178	48	9	April 12	28	7	149
„ „ „	178	48	9	Dec. 4	42	6	135
Barrow Hedges (A.) . . .	200	69	7	„ 4	46	1	154
„ „ (B.)	..	64	6	..	..		..
Little Woodcote	320	189	9	April 7	155	0	165
Woodcote Grove	450	313	0	Dec. 4	296	6	153
Beddington Parish.							
Woodcote Lodge	250	122	3	April 7	88	3	162
Windmill Cottage	210	..		Dec. 12	51	3	158
New Barn Farm	230	..		April 7	64	7	165
Keeper's Lodge	308	167	7	Dec. 12	139	3	168
Russell Hill	360	287	0?	„ 5	251	0?	110
Croydon Parish.							
Croham	270	79	8	Nov. 27	71	5	198
Old Stables near Red Deer .	180	25	4	Dec. 3	19	10	160
Selsdon Farm	450	245	0	..	..		..
Selsdon Park	525	[425]	0	..	..		..
Kingswood Lodge. . . .	550	180	0	..	..		..
Addington Parish.							
Addington	265	73	2	Nov. 27	53	11	211
Addington Lodge	490	[397]	0	„ 27	204	0	286
Farley Parish.							
Sampson's, Farley Green. .	540	154	4	..	..		..
Warlingham Parish.							
Crewe's Farm	550	..		..	..		..
Kennel Farm	600	290	10	..	..		..
Well Farm	330	112	0	..	..		..
Godstone Parish.							
Marden Park Farm . . .	..	..		..	..		..
Birchwood House	470	209	0	..	..		..
Chelsham Parish.							
Hallelu Farm	408	117	0	..	..		..
Bughill Farm	375	124	0	..	..		..

East of the **Mole**. **Measured** by J. **Lucas**.

Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.	
1874	Ft. Ins.	Feet.	1875	Ft. Ins.	Feet.	1876	Ft. Ins.	Feet.	Feet.	1874 °	1876 °
..	..	..	..	..	..	Mar. 29	67 0	133	..	..	..
..	..	..	..	..	..	Oct. 24	To stage, 61 feet dry		..	..	..
..	..	..	..	..	..	Mar. 29	34 10	143	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	Mar. 29	52 4	..	..	..	..
..	..	..	..	..	..	„ 29	47 0	..	..	..	..
..	..	..	..	..	..	„ 29	162 8	158	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	May 27	68 6	201	Apr. 28	63 9	206	..	..	..
Nov. 11	23 4	156	„ 25	15 8	164	Jan. closed.		..	156	50·5	..
..	..	..	..	..	..	Apr. 28	186 0	264	206	..	50·5
..	..	..	..	..	..	„ 28	..	..	210	..	50·5
..	..	..	..	..	..	„ 28	146 8	403	371	..	49·5
..	..	..	May 27	46 10	218	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	Apr. 28	139 5	401	387	..	50·0
..	..	..	..	..	..	Apr. 28	248 8	301	..	..	49·8
Nov. 17	278 6	321	..	..	..	„ 28	243 5	337	310	..	49·5
„ 17	90 0	240	..	..	..	„ 28	15 4	315	..	..	..
Nov. 11	175 feet to staging, dry.		..	..	..	..	..	..	..	..	..
„ 11	quite dry.		..	..	..	Apr. 28	131 2	339	..	..	..
..	..	..	..	..	..	Apr. 28	70 0	338	292	..	49·5
Nov. 11	quite dry.		..	..	..	„ 28	38 2	337	..	..	..

TABLE 12.—CHALK WELLS in KENT. WEST of

——	Height of Well Mouth.	Depth of Well.	Dates.	Depth to Water.	Height of Water-line.
	Feet.	Feet. Ins.	1874	Feet. Ins.	Feet.
Cudham Parish.					
Newbarn	512	..	Nov. 17	Dry at 223.	
New Houses	288	115 0	..	..	..
Downe Parish.					
North End	305	131 0	Nov. 9	128 6	176
High Elms Farm	..	..	„ 9	To stage dry, 125 ft.	..
Public Well	..	..	..	..	..
Farnborough Parish.					
Farnborough Hall . . .	..	165 0	Nov. 9	162 0	..
Public Well, Green Street Green	254	78 6	„ 9	78 0	176
Denbarn	276	101 0	„ 9	97 0	179
Chelsfield Parish.					
Queen's Head, Green Street Green	..	79 4	..	..	..
Chelsfield Station	..	..	..	..	..
„ Rectory . . .	..	200 0	..	..	..
Court Lodge	446	275 0	..	..	..
Slutt's Hole	446	270 0	..	..	..
Halstead Station, sinking .	..	..	..	..	..
Grange Farm	329	160 0	..	..	..
Bull's Head, Pratt's Bottom .	..	173 0	..	..	..
Orpington Parish.					
Cock Mannings	235	84 0	..	..	..
New Town	170	13 9	Nov. 7	10 0	160
Well 430 yards S.E. of Orpington Church	210	45 4	„ 7	42 10	167
Tripe Farm	270	96 8	„ 7	Dry.	..
Rooks Grove Farm . . .	..	16 0	„ 7	Dry.	..
Broom Hill.	204	41 9	„ 9	41 3	162
Cottage, Orpington . . .	..	18 6	..	..	..
Railway Bridge	211	47 0	..	..	..
Farm S. of do.	217	46 0	..	..	..
Brickbat Row	..	57 8	..	..	..

the DARENT. MEASURED by J. LUCAS.

Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.		
1875	Feet. Ins.	Feet.	1876	Feet. Ins.	Feet.	Feet.	1874 °	1875 °	1876 °
..	..	..	..	..	..	..	..	..	..
May 29	98 0	190	..	..	..	..	..	..	..
May 27	106 6	198	..	..	..	175	50·5	..	..
..	..	..	..	..	..	..	..	..	..
May 27	To staging 164 feet; dry at that depth.		..	..	..	..	..	..	..
..	..	..	..	..	..	..	51·5	..	..
May 27	62 4	191	..	..	..	..	..	..	..
„ 27	81 3	194	..	..	..	176	50·5	..	..
May 27	59 4	..	..	..	..	..	..	..	..
..	..	..	Mar. 30	139 0	..	..	..	..	..
..	..	..	„ 30	..	..	..	..	..	..
..	..	..	„ 30	255 8	190	..	..	..	..
..	..	..	„ 30	248 10	197	..	..	..	..
..	..	..	Feb. 19	..	..	..	..	..	..
..	..	..	„ 19	124 0	205	..	..	..	..
May 29	134 8	..	„ 19	128 0	..	..	..	..	..
..	..	..	Mar. 30	69 8	165	..	..	..	..
..	..	..	..	..	..	158	52·5	..	..
..	..	..	..	..	..	166	50·5	..	..
..	..	..	Mar. 30	86 6	183	175	..	..	..
..	..	..	..	..	..	..	..	..	..
May 27	36 8	167	..	..	..	164	50·5	..	..
„ 27	11 0	..	..	..	..	..	..	..	..
„ 27	31 3	179	..	..	..	..	..	..	..
„ 27	33 6	183	..	..	..	..	..	..	..
„ 27	40 8	..	..	..	..	..	..	..	..

TABLE 12 (*continued*).—CHALK WELLS IN KENT.

——	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	
	Feet.	Feet.	Ins.	1874	Feet.	Ins.	Feet.	Ins.
St. Mary Cray Parish.								
Station	200	75	6	Nov. 7	71	6	128	0
„	200	75	6	„ 9	71	6	128	0
Halstead Parish.								
Wheatsheaf Farm	420	161	0	Nov. 16	140	6	279	6
Eynesford Parish.								
Crockenhill (A)	..	123	0	..	..		..	
„ (B)	264	114	2	Nov. 10	110	0	154	0
„ (C)	..	133	10	..	..		..	
Well N.E. of Baptist Burial Ground (D)	..	138	6	Nov. 10	133	6	..	
„ S. W. of do. (E) . . .	..	142	0	„ 10	139	0	..	
Dalton's Farm (F) . . .	310	150	8	„ 10	143	0	167	0
Cacketshill Cottages . . .	320	183	8	„ 10	173	0	147	0
Wested Cottage	335	195	8	„ 10	191	0	144	0
Little Westwood	350	..		„ 10	220	0	130	0
Lullingstone Parish.								
Park Keepers', Lullingstone .	350	210	0	Nov. 16	202	0	148	0
Shoreham Parish.								
Little Crockerhirst . . .	410	217	10	Nov. 16	215	6	194	0
Timberden	..	118	0	..	..		..	
Colegates	510	183	0	Nov. 16	181	0	329	0
Twitton (B)	262	34	0	..	..		..	
„ „	262	34	0	..	..		..	
„ (C)	256	24	5	..	..		..	
„ „	256	24	5	..	..		..	
Otford Parish.								
Little Dunton (goes to Upper Greensand)	295 295	49 49	3 3	.. ..	.. ..		.. ..	
Twitton (A)	285	57	0	..	..		..	
„ (A)	„	„		..	..		..	

West of the Darent. Measured by J. Lucas.

Dates.	Depth to Water.	Height of Water-line.	Dates.	Depth to Water.	Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.		
1875	Feet. Ins.	Feet.	1876	Feet. Ins.	Feet.	Feet.	1874 °	1875 °	1876 °
May 27	69 5	131	Mar. 30	67 6	132	126	50·5	..	..
..	..	..	..	..	..	126	50·5	..	..
May 29	140 0	280	Feb. 19	134 0	286	260	50·5	..	..
May 29	109 11	..	Feb. 19	108 10	..	..	..	50·7	..
„ 29	107 4	156	„ 19	104 6	159	151	50·5	50·5	..
„ 29	123 8	..	„ 19	124 4	..	..	..	50·5	..
..	..	..	„ 19	127 4	..	..	50·5	..	..
..	..	..	..	..	..	..	50·5	..	..
May 29	141 0	169	Feb. 19	138 3	172	160	50·5	50·5	..
„ 29	177 0	143	..	..	..	138	50·7	50·5	..
„ 29	189 0	146	Feb. 19	187 4	148	141	50·7	..	..
„ 29	219 0	131	„ 19	215 0	135	..	..	..	..
May 29	200 0	150	Feb. 19	197 10	152	141	50·5	..	..
May 29	213 6	196	Feb. 19	210 11	199	193	50·5	..	..
„ 29	110 0	..	„ 19	107 4	..	..	..	50·5	..
„ 29	181 0	329	„ 19	180 6	329	327	..	50·5	..
..	..	..	Mar. 9	18 0	244	229	..	..	49·6
..	..	..	Nov. 3	29 6	233	..	..	..	..
..	..	..	Mar. 9	14 2	242	232	..	..	49·6
..	..	..	Nov. 3	24 9	..	..	..	..	..
..	..	..	Mar. 9	34 9	260	247	..	..	49·1
..	..	..	Nov. 3	48 2	247	..	..	..	..
..	..	..	Mar. 9	41 0	244	229	..	..	49·6
..	..	..	Nov. 3	53 8	231	..	..	..	..

TABLE 13.—CHALK WELLS in KENT. EAST of the DARENT.

MEASURED by J. LUCAS.

—	Height of Well Mouth.	Depth of Well.		Dates.	Depth to Water.		Height of Water-line.	Altitude of Point of Observation.	Temperatures. Degrees Fahr.
	Feet.	Feet.	Ins.	1876	Feet.	Ins.	Feet.	Feet.	°
Eynesford Parish.									
Lower Austin Lodge .	220	78	0	Sept. 23	68	0	152	..	..
Bower Farm . . .	420	290	7	„ 23	267	10	152	130	51·0
Upper Austin Lodge .	278	134	11	„ 23	124	1	154	144	51·0
Shoreham Parish.									
Dunstall Priory . .	346	176	7	Sept. 23	174	4	172	..	..
Cottage near Cob Hall	290	129	8	Nov. 3	127	0	163	..	..
Magpie Bottom . .	445	198	8	Sept. 23	196	8	253	248	50·5
Kingsdown Parish.									
East Hill	573	..		Sept. 23	315 feet of line did not reach water.				
Natt's Farm . . .	372	139	6	„ 23	130	0	242	..	..
Hever Place . . .	530	..		„ 23	315 feet of line did not reach water.				
Manor House . . .	560	214	4	„ 23	210	0	350	..	..
Wrotham Parish.									
Woodlands	488	168	4	Sept. 23	145	4	343	..	..

TABLE 14.—HEIGHTS ABOVE ORDNANCE DATUM of some of the WELL MOUTHS INCLUDED in TABLE 11. FROM LEVELLINGS by MR. BALDWIN LATHAM, M. INST. C.E.

Parish.	Name of Well.	Elevation in Feet.	Parish.	Name of Well.	Elevatio in Feet.
Epsom . .	Grand Stand. . .	426·35	*Coulsdon (con.)*	Hope Cottage . .	247·8
Ewell . .	Priest Hill Farm .	219·80	„ . .	Red Lion. . . .	251·0
„ . .	Longdown Cottage .	231·09	„ . .	Marlpit Lane . .	278·8
„ . .	Northlieu Farm . .	260·63	*Woodmansterne*	Woodmansterne, P.W.	462·1
Cuddington	Walnut-tree Farm .	312·92	„	Stagbury	325·1
Cheam. .	The Folly . . .	310·82	„	Shepherd's Cottage.	268·1
Sutton . .	Turf Cottage. . .	334·72	„	Little Woodcote . .	321·6
Banstead .	Banstead Parish Well	522·41	„	Woodcote Grove. .	448·8
„ .	Apsley Cottage . .	526·05	*Beddington* .	Woodcote Lodge. .	252·9
Chipstead .	Well House . . .	433·00	„ .	New Barn Farm. .	229·3
„ .	Pigeon House Farm.	393·44	„ .	Keeper's Lodge . .	307·2
„ .	Rumbold's Castle .	344·24	„ .	Russell Hill . . .	364·9
„ .	Hooley Cottage . .	361·21	*Croydon* . .	Croham Villas . .	265·2
Merstham .	Jolliffe Arms. . .	377·02	*Addington*. .	Addington Lodge .	491·3
„ .	Harpsoak Cottage .	447·46	*Warlingham* .	Kennel Farm . .	605·6
„ .	Dean Farm . . .	429·05	„ .	Well Farm . . .	333·0
Coulsdon .	Tudor Cottages . .	213·99	*Godstone* . .	Birchwood House .	472·7
„ .	Flint Cottage . .	231·33	*Chelsham* . .	Bughill Farm . .	375·4

[MR. LUCA

Mr. LUCAS wished to explain some matters that had not been very clearly put in the Paper. The Chalk Marl, forming the base of the system described, was indicated on the map (Plate 3) by a black band which showed its outcrop. He had walked along that outcrop the whole distance between Guildford and the village of Kemsing, in Kent, and was satisfied that the line might be taken as correct. The continuity of the outcrop was, he believed, only broken near Guildford, and once or twice between Guildford and Dorking. At Tandridge Hill there was a large fault with the down-throw on the west, and another with the down-throw on the east, west of Titsey Park. Neither of these was marked on the Geological Survey map. He had never been able to find a fault at Merstham indicated on that map. He had also himself drawn the line of the Tertiary base, and he believed that it was correct. It was essential to have those two lines correct. It was impossible to measure by any practical means the thickness of the Chalk, but there were means of arriving at an approximation. Without some knowledge on that point, sections could not be properly drawn; and if they were not so drawn, the Chalk Marl and the line of abutment would not be shown in the right position; and this would have the effect of making the zone, which he had asserted to be without water, too wide or too narrow, according as the dip of the Chalk Marl was taken at too small or too great an angle. The thickness of the Chalk on the area in question was about 750 feet. There was something more positive in the case of a section across the range of hills between Guildford and Dorking, and that line of section ran from a point between Wootton and Abinger Hall, to Leatherhead. There were on it three wells that passed through the Chalk into the Upper Greensand. The first of these was Lady Caroline Maxse's Effingham Hill Lodge well; the second was her Laundry Farm well, and the third, Sir Walter Farquhar's well, at Polesden Lacy. Those wells had traversed the whole thickness of the Chalk, and had not derived from it any water, but they served to fix the position of the Malm rock of the Upper Greensand at those points, and from that the position of the Chalk Marl; therefore the thickness of the Chalk had been estimated by that section. The sections (Plate 4) agreed exactly with those published by the Geological Survey of England, and he had no reason to suppose that they were otherwise than correct. The influence exerted by the dry valley systems on the form of the water-surface underneath had been only briefly referred to in the Paper. The Green Dene valley, running from the Tertiary base up to the summit of the escarpment, appeared to have been formed along a line of weakness, probably fissures, the line of weakness being seen again on the southern side on the face of the escarpment, and it had had the effect of lowering the water-surface to a remarkable extent. The mode in which the position of the water contours and that of the line of abutment had been determined was obvious. The depths to the water-surface having first been determined by actual measurement, and the contours of the ground having been taken from the 6-inch Ordnance maps, there could be no doubt as to the position occupied by the water-line in each well. He had only been able to put a maximum line on one of the sections. The sectional area of variation was shown by dark blue (Plate 4), and the water in the Chalk at the minimum by light blue. The plates were both coloured for a minimum epoch, the materials not being perfect enough to enable him to draw the contours for a maximum epoch. Over a portion of the district, ranging from Epsom to Croydon, he might have added the maximum line for the 200-feet contour, but he thought that would disfigure the map, unless the same thing were done for the whole. A line which ought to have been put on the maps had not been drawn—the line of intersection of the two planes of the water-line in its minimum and maximum position. This would pass through the springs at Ewell, Carshalton, Croydon, &c. From the line on the northern side there started a third plane, which he called the artesian plane, marking the height to which the water would rise from the Chalk through the artesian borings. The science of geology might be divided under four heads. The first, and by far the most important, was physical geology, which had developed into something like a distinct science only in recent years. Physical geology treated merely of the crust of the earth, the rocks which formed it, their dip and position. As subdivisions of physical geology came mineralogy and palæontology. The second of the four main divisions was agricultural geology, treating of the rocks after they had become decomposed by meteorological influences. Then came hydrogeology, a science not yet four years old, and lastly, sanitary geology. It had often been asked why such work had not been done by the Geological Survey. The answer was that it was not their business. Sir Henry de la Beche's survey undertook nothing more than mapping the physical lines, to show the position of the outcrop of the various strata forming the earth's crust. Where Sir Henry's survey ended, his commenced. The province of hydrogeology began where physical geology and meteorology ended.

The Rev. J. C. CLUTTERBUCK complimented Mr. Lucas on his diligence in collecting the facts given in the Paper. Reference had been made to the circumstance that Mr. L. Woods, Mr. Bland and himself had been early engaged in hydrogeology. Mr. Bland had made many observations, which Dr. Buckland had placed in his hands, and had asked him to reduce to sections, which he accordingly did. The lines which Mr. Bland had noticed were in Kent; one from Upchurch through Hartlip to the Maidstone river, and the other from Sittingbourne to Freebourne Mill Pond. They both passed from the Tertiaries across the Upper and Lower Chalk into the Greensand. He was able by these to show the line represented by the surface of the water in the Chalk, which he then ventured to call the water-level—now called the water-line by others. The lines were interesting and instructive, as showing the great angle at which the water lay in the Lower Chalk. The Author had described exceedingly well the difference between the Upper and the Lower Chalk; the Upper being known by the bands of flints it contained, which were absent from the latter. He said truly that there was far less water to be obtained from the Lower than from the Upper Chalk. That would act in some measure as a warning to those who had ventured to assert that the water in the Chalk was inexhaustible. It might be said that the water from the lower depth came more quickly through bore-holes or shafts; this was no doubt the fact, as it rose under greater pressure; but coming more freely it had a tendency to drain the stratum more rapidly. It would be remembered that a Paper had been read before the Institution by Professor Ansted, who had submitted specimens of chalk to water, and thus determined accurately the amount of water which chalk would absorb. One point was often overlooked, namely, the condition of the Chalk in the earth. It would be found by experiment, alternately saturating and drying a piece of chalk, that it took up exactly the same quantity every time. Some persons supposed that the water passed through the body of the Chalk itself, but this was not the case. A hollow piece of chalk would, after saturation, contain water like any ordinary vessel. Water passed, not through the body of the Chalk, but through the fissures, cracks, and crannies, so numerous in the Upper Chalk, especially under the line of flints, but in the Lower it existed only as described in the Paper. How could one account for the water falling upon the surface being so small in quantity compared with the large body of chalk through which it had to pass, and which might be expected to absorb the whole, except that the Chalk below a certain level was so saturated that it could take up no more?

Thus, immediately the soil above the Chalk, or the Chalk itself, was saturated, it was in a condition to pass all the water to the lower part where the water-line existed. That being the case it was possible to measure to a certain extent the amount of water by a periodical measurement of wells. As soon as there was a rise in the water-level, when there was perfect saturation of the surface it would be found that this rise was very rapid, though it was generally supposed to take a long time before any water reached the water-level. He had known water in a deep well rise 5 feet in a day. After a heavy rain the water sank, because there was nothing to impede it, as it found the Chalk below so thoroughly saturated that it could not take up any more. The fact of the water in the Lower Chalk being less than in the Upper needed no proof. He had been in some deep wells in London with the late Mr. Frederick Braithwaite, and had seen the very thing of which the Author had spoken. The subject of bournes, he believed, had also been misunderstood. He had taken considerable pains in making careful levellings of various valleys in which the bournes ran, and he had found that the bursting of the bourne was due to the line of water underground rising at a greater angle, after rain, than the soil itself. There was often a dip a certain way up the valley where it took its rise, and it came rattling down by the channel generally provided for it. In several places which he had examined, he had been able to predict almost the very day on which the bournes began to run.

Professor Ansted said he fully appreciated the advantage of having on record a large number of observations over a considerable extent of country, with the newest and most accurate contour maps, and thus enabling sections to be made which could not be produced in any other way. A collection of observations upon deep wells, and especially upon draw-wells, was very valuable. Few of the main facts brought forward had not been previously noticed by geologists and engineers. The term hydrogeology, which the Author had adopted, was very well in its way, but as a mere word it meant no more than the branch of geology that had reference to water in rocks. The application of geology to the consideration of the body of water lodged in the various strata was by no means new. Those who had been engaged in the water question could look back to twenty or thirty years of personal observation in the matter. They were long ago aware that water stood in the Chalk in levels which had some reference to the position of the Chalk and the nature of the stratification, and that was almost all that could be said even now with the advantage of the present maps and sections. It was quite true that to be able to draw a line which should connect the different water-levels was a very important matter. It had been done long ago for the New Red Sandstone in various places, and to some extent in the Chalk. It was now done to a still greater degree, and with the same results. With a stratum like chalk, which was itself somewhat spongy, absorbing a large quantity of water, lying over a mass of material, part of the lower portion of the Chalk itself, being not altogether spongy and very retentive, and the bed underneath the Chalk also being exceedingly retentive, the lower members of the Chalk became choked to a certain extent, and the water rested in them, so that they must necessarily partake of the nature of a basin. The water was contained in the hollow part, and stood there under all circumstances. The level at which it stood must also have reference to the vicinity of the outcrop, because if the water rose over the edge of the basins, it would form springs along the line of the outcrop on either side, and in that way the level would be kept up. That this was the case with the Chalk had been known long ago. That was the main point determined by the observations of the Author, which thoroughly confirmed all that had been done before. The Author very properly alluded to the views entertained with regard to chalk, as containing an almost indefinite supply of water, which could be got at by exhaustive pumping. Many geologists and engineers would agree with him that that exhaustive pumping from the Chalk not only must affect the wells in different parts of the Chalk, but must ultimately exhaust the supply. The quantity of water entering the Chalk from the surface was very large, but the evaporation from the surface was enormous. The evaporation from the surface of all rocks was great, even from clays; and that from hard limestone was almost beyond belief; but evaporation from the surface of chalk was practically unlimited, it would bring the water from the bottom. The whole mass of the Chalk might be practically dry at the top for a considerable depth, and yet evaporation would go on steadily and continue to remove the water from the bottom. The evaporation in a year would probably be at least equivalent to the rainfall of a year, and the accumulative supply in the mass of chalk would in that way be soon exhausted. On that point he agreed with the Author. There was but a small amount of water below the water-level practically available compared with the enormous quantity present in the mass of the Chalk, but not available; and that should set at rest the question of looking to the Chalk as the great source of supply for large cities, especially for London.

Mr. HOMERSHAM thought that the members were much indebted to the Author for his interesting record. The area in question had a considerable interest for all persons concerned in the supply of water from the Chalk. Five sets of waterworks had, for the last fourteen to twenty-four years, derived a supply of subterranean chalk water from that limited area: the Caterham, the Croydon, the Kent, the Kenley, and the Sutton Works. There were wells yielding considerable quantities of water situated at Bromley, supplying the Kent Company; at Caterham, supplying the Caterham Company; at Charlton, Crayford, Deptford, and Plumstead, supplying the Kent Company; at Croydon, supplying the Croydon Local Board; at Kenley, supplying a small company there; and at Sutton, supplying the Sutton Company. These works collectively had not raised less than 10,000,000 or 11,000,000 gallons a day, so that the amount of water derived from the Chalk in that area for many years was very large. The wells were really capable of yielding 15,000,000 or 16,000,000 gallons a day, but of course the companies did not usually pump up more than their consumers required. There was one point in the Paper with which he could not agree. In the chalk hills south of London the water at its maximum stood 400 feet above Ordnance datum. In a well that he had sunk at Caterham in 1860, the water, in the high-water seasons of the year, after a series of wet years stood at that height; and, in the low-water seasons of the year, after a series of dry years it stood 300 feet above Ordnance datum, showing a variation of 100 feet. The well was situated about 1¼ mile north of the Gault clay. At Croydon, however, a distance of 6¾ miles farther north, there was very little variation in the water-level—not more than a foot or two. The top of the Caterham well was about 700 feet above the sea, and the top of the Croydon well about 150 feet; the surface of the subterranean water in the hills on the south declining in the lower ground to the north assumed the form of an inclined plane, in the course of which there were intermediate wells having their water at intermediate levels. There was a maximum fall of about 37 feet per mile between the normal top water-level in the North Downs and the outcrop of the Tertiaries near Croydon, and a minimum fall of about 24 feet. He understood the Author to assert that he found a steeper incline in full-water seasons than in wet; but that was contrary to Mr. Homersham's experience. In the Chiltern hills, to the north of London, the normal maximum height he had known in the waterworks well sunk through the Chalk till it reached the Gault clay was 513 feet above Ordnance datum. This was after a series of wet years, and the lowest level after a series of dry years was 469 feet; so that there was nothing like the same amount of variation in the level of the subterranean water of the Chiltern hills as in the North Downs. In the well at Bushey, reported upon by Mr. Robert Stephenson in 1840, the subterranean water stood at a normal level of 181 feet, from which there was hardly any variation. The distance between the well in the Chiltern hills and the Bushey meadows to the south was 15 miles, and the fall of the water-level from the Chiltern hills at its maximum was 22 feet per mile, and at its minimum 19 feet. Along the outcrop of the Chalk in the area referred to by the Author, it was cut through by the Darent, the Mole, and the Wey. Where the water from the north flowed through the outcrop at the Darent, the level of the Chalk was 210 feet above Ordnance datum, at the Mole 128 feet, and at the Wey 109 feet; yet the water in the interior of the higher portions of the hills near to their escarpment stood 400 feet above Ordnance datum in wet years, and not less than 300 feet in any year.

With regard to the statement that it was wrong to sink a well or drive a bore-hole into the Chalk in order to get a large supply of water, he would point to the five sets of waterworks to which he had referred, supplied by eight or nine wells, some of them yielding 3,000,000 or 4,000,000 gallons a day, and all of which had bore-holes, and many of which had no lateral adits. The yield of the wells supplying the Kent and Croydon Companies was enormous. The water was taken almost entirely from bore-holes, and the same was the case at Caterham. A bourne might be looked upon as an overflow from the Chalk when the lowermost mass of it was saturated with water. When the stratum was saturated the water would rise, but not at any one point in particular. At Caterham, for instance, the water rose first in the Godstone quarries, near the outcrop of the Gault clay. The whole base of the Chalk itself was saturated, and wells 100 feet deep that had been dry, say at Warlingham, became gradually filled with water. During the last fifteen or sixteen years the Kent Company had pumped all their water from the Chalk, and the Croydon Board for a much longer period; and if such pumping had any practical tendency to exhaust the water in the Chalk hills, the supply would not have continued so abundant; but the surplus water was found running away in bournes, so that there was no indication of the pumping affecting the wells in the district or drying up the country in any way. The Author had spoken of the subterranean water resting upon the Chalk Marl instead of upon the Gault clay. The fact was, there was no such continuous bed of Chalk Marl as there was of Gault to warrant the assertion that the water reached down to that point and not lower. The Marl was intersected with vertical fissures, and a large body of water passed down those fissures, and got into the Lower Chalk and Upper Greensand, which last might be considered chalk for water purposes. After sinking a well in the Chiltern hills down 70 or 80 feet below the line of saturation, he had bored down to the surface Gault, and the water then rose through the bore-hole into the bottom of the well, a large quantity being obtained in that way. At Caterham the bottom of the well was 170 or 180 feet below the line of saturation in wet seasons, and 70 or 80 feet in dry seasons. Borings here had touched the Gault clay, and from the Upper Greensand springs of water also rose into the bottom of the well. All geologists except the Author had treated chalk as saturated with water down to the Gault clay, and he thought there was no good reason for altering the practice that had been heretofore adopted. As a practical illustration of what could be done by boring he might mention that at the head of the river Ver, which was 293 feet above the mean level of the sea, the mill-owners were very short of water in dry seasons, and they inquired the best way of getting an extra supply. The late Mr. Robert Paten said he would produce 700,000 gallons per day. He accordingly sank five bore-holes, driving lines of cast-iron pipes, 12 inches in diameter, into the solid chalk, making the bottom hermetically tight, so that no water could escape into the gravel and broken chalk near to the surface that covered the Chalk. He then bored down 250 feet, and the result was that the water overflowed 290 feet above the sea, producing 700,000 gallons a day, which ran into the bed of the Ver. He had himself examined the water from the bore-holes only a year and a half ago, and found it running in the same manner as at first.

Objection had been taken by the Author and Professor Ansted to the idea of London being supplied with water from the Chalk, but what were the facts? The Kent Water Company fourteen years ago obtained the whole of their water from the river Ravensbourne, but ever since their whole supply had been obtained from the Chalk. The New River Company obtained its extra supplies from wells, yielding 8,000,000 or 9,000,000 gallons a day, and London and the suburbs were now gradually being supplied with water from wells in the Chalk. It was said in 1850 that before long there would be no more water in the well in Trafalgar Square, but it yielded now as much as it did then, or even more. No Company had lost any water that it originally had. All were able to obtain a larger supply as they required it. As a rule, the operation of pumping tended to increase the quantity. He remembered that many years ago, when he was concerned for the Brighton company, in the adits driven out from the well, little fissures, into which a penknife could hardly be put, in process of time were considerably enlarged; for as the water was drawn through such fissures they became enlarged, and the quantity yielded was thereby increased. He referred especially to wells where the Chalk was not covered with a stratum of London clay. Where it was so covered the case was different; the Chalk was much harder and less porous, and the water was of a different quality. There were 3,600 square miles of chalk cropping up at the surface within a distance from which water could be readily obtained for the supply of London. The well sunk at Croydon, and completed in 1854, yielded about 2,100 gallons a minute, or 3,000,000 gallons of water a day. Croydon did not require that amount of water, and the well was pumped at the rate of about 2,100 gallons a minute for twelve or fourteen hours a day. Another well had since been sunk there, lined with cast-iron cylinders from the surface down and into the more solid chalk below, and a third was being sunk in a similar manner. While pumping 3,000,000 gallons a day the normal level of the water was lowered only about 14 feet. The water-level at the wells at Croydon was now the same as it was in 1854, notwithstanding the continuous pumping from the well. The whole of the water was derived from borings. The area of the country alluded to by the Author was stated to be 200 square miles. His own calculation was that the country where the Chalk was exposed to the surface was only about 150 square miles. The area round London, however, was about 3,600 miles, so that even the former only represented one-eighteenth of the area from which water could be drawn. From 11,000,000 to 12,000,000 gallons daily had been actually used during the last fifteen or sixteen years from the small area of 150 square miles, which would give some notion, not of the theoretical, but of the actual water-yielding capacity of the district. Since the well at Croydon had been at work, there had been two powerful bournes, one in 1866 and the other in 1873, showing that in those years the Chalk was saturated to overflowing. No one therefore could say that the pumping of so large a quantity of water, from the limited area to which he had referred, had interfered with the supply of water in that district. The Author had alluded to 1 foot of rain raising the water in a well one hundred and twenty times the depth of the fall. That might be so in certain elevated parts near to the outcrop of the Gault, but it arose in this way. Where there was a line of saturation in the Chalk strata, a layer of chalk immediately above it was not quite saturated, say nine-tenths, another eight-tenths, another seven-tenths, and so on. The pores of the Chalk were held by capillary attraction nearly full, but not quite. When the rain-water was sinking down from the surface it would gradually saturate the partially filled pores, before it would percolate through, and sink to lower levels. That was the reason why, in certain seasons of the year, with a small fall of rain there was a large rise in the water-level.

Mr. **Evans** wished to say a few words with regard to the statistics mentioned by Mr. Homersham, who stated that around London there were 3,600 square miles of chalk country available for water supply. The Commissioners on the Pollution of Rivers, who had entered into the question at considerable length, reported that there were 849 square miles of such country within 30 miles of London, showing a discrepancy which might possibly be explained.[1] Mr. Homersham had alluded to the supply of water derived from borings near Redbourn. He had more than once visited those borings, and on one occasion when they were calculated to throw a considerable amount of light on the nature of the passage of water through the Chalk. He was tracing the course of the Ver, in close vicinity to which stream the borings were sunk. He found the Ver running 2 or 3 miles above Redbourn, and following it he found the river gradually die in its bed, and for ½ mile from the borings the bed was dry, but when he reached the borings there was a fair flow of water coming out of them. The inference that he drew was, that those borings had tapped fissures in such a manner that the water of the Ver instead of flowing above ground had found a more ready access to the borings below ground, and, in fact, that instead of flowing in its bed, the waters of the stream, after sinking for a time, again found their way to the surface through an artificial bore-hole. With regard to the statement that the occasional flow of a bourne proved that the abstraction of water from a district did not affect the water supply, he thought that any one who considered for a moment would see that that was an argument which would not "hold water," for though, on an average, there might be a percolation of water into the Chalk of, say, 6 inches per annum, occasionally there might be one or two years in succession of percolation of from 10 to 12 or 14 inches; and in those cases, the supply being so far above the average, the bournes would run, and yet during ordinary or short seasons the abstraction of water from a bore-hole might be severely felt. With regard to the Paper itself, the Author did not state in what manner the years were reckoned, but it was probably from January 1st to December 31st. For all hydrogeological purposes, however, he thought it would be a great advantage if the year were divided into two periods, say from October 1st to March 31st, during which there was but little vegetation, and generally a rather larger amount of rain than during the summer months; and from April 1st to September 30th, during which there was a great amount of vegetation and evaporation, and in which, according to experiments tried by Mr. Greaves, Mr. Dickinson, and others, but little water found its way through a depth of 3 feet of soil. The Author stated that there were no tests as to the capabilities of chalk for water. On that point he differed from him, partly because some tests for the capabilities of chalk were afforded by the experiments to which he had alluded, and partly because in inland districts, where the sole escape of the water that found its way into the Chalk was through the springs, a gauge of the amount of water would be afforded by the streams, which it was evident must carry off all the superfluous water that found its way into the Chalk. The Author also said: "Not every fissure cut by a well below this line is water-bearing. It is easy to conceive, in explanation of this, the existence of independent systems of fissures isolated from those to which rain-water finds access." He thought there must be some misuse of the English language in that sentence, because he could not imagine that the Author would infer that there existed any springs below ground which were not originally derived from the rain-water falling upon the surface. Though there might be channels which had more ready access to the reservoir of water at a higher level in the Chalk, yet it was too much to say that there was no access to supplies of water derived from the rainfall. With regard to the bournes, the Author stated that they were confined to the Lower Chalk. In that again he disagreed with him to some extent. It was difficult, of course, to define which was the Lower Chalk and which the Upper, as they shaded off one into the other, and even in the Lower Chalk, as reckoned by geologists, flint occasionally occurred; but in chalk, which might be regarded as middle chalk, in Hertfordshire, there was a bourne which followed much the same laws as those at Croydon, but flowed perhaps more frequently. That bourne had flowed this year with a smaller amount of percolation through the Chalk than ordinary, in consequence of the amount of rain during previous years having supplied the underground reservoir to such an extent as to raise what was termed in the Paper "the water-line." Another point deserving attention in connection with questions of the kind was the angle of friction of water in the Chalk. That would vary very considerably, not only according to the character of the chalk, whether Upper, Middle, or Lower, but also according to its fractured character. To the north of London the angle of friction in the Chalk might be considered in the lower part of the course of the rivers to be represented by a gradient of 12 feet 6 inches to the mile; higher up, getting into the Lower Chalk, the gradient was 19 feet 6 inches; but in the neighbourhood of Dover and other places the angle was as much as 40 feet to the mile. It was evident that there must be such an angle, and that it could not be less than he had stated, because the streams flowed upon the surface. If the angle of friction were 10 feet, and the inclination of the valleys 15 feet, the water would often find its way more readily under ground than above ground, and the streams would disappear. The amount of friction had much influence upon those dome-shaped masses of water, or those subterranean hills, as he had called them, which were found under the chalk hills in places between two valleys into which springs outflowed. The variation of the water-level pointed out in the Paper was, he thought, one of its most important features. He had observed in parts of Hertfordshire variations between one year and another to the extent of 70 feet in wells at a considerable distance from any streams or springs. The Author, however, cited even greater variations in the level of water, and pointed out how a comparatively small amount of rain filtering into the ground occasioned a large amount of rise in wells. He thought that Mr. Homersham's explanation, that the Chalk was to a certain extent already saturated, was a very good and true one, but it was also the case that in the Lower Chalk the amount of pores and fissures was considerably less than in the Upper Chalk, and therefore that the rise was, under such circumstances, much higher than where the fissures and pores were larger in amount. With reference to the general question as to the amount of water derivable from the Chalk, there could be little doubt that it was entirely dependent upon the depth of rain absorbed. One might for a certain length of time draw from the subterranean reservoir which existed, and imagine that one was getting a boundless supply, but the day must come when the underground reservoir would be exhausted, and when one would have to depend upon the amount of rain finding its way through the surface into the lower depths. That, as ascertained by experiments, could not safely be taken as more than 4 inches per annum; but allowing an average of 6 inches per annum, it would be found that in order to supply the present consumption of London, irrespectively of the water derived from the Kent Water Company, the whole rainfall upon an area of 440 miles would be required. He had entered at considerable length into that question in the last anniversary address which he had delivered before the Geological Society, and he would not now enter into further details. He would merely draw attention to the fact that an abstraction of the spring-water from an area of 440 square miles could not be effected without a considerable amount of inconvenience and loss to those who lived upon the area which it was proposed to drain.

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[1] *Vide* Sixth Report, "The Domestic Water Supply of Great Britain," p. 298. London, 1874.

Mr. Shelford said the Author had ably collated certain experiments, for which he felt grateful. In considering the practical conclusion at which he arrived, and which more than anything else concerned engineers, he found that the Author was disposed to doubt, if not to dispute, the vast storage capacity of the Chalk. He had had no experience of the area of which the Author treated, but he had had something to do with the detached part of the same Chalk Water System, forming the slope of the South Downs. He said "detached," because it was well known to all acquainted with the subject that the North and South Downs formed reverse slopes of the great anticlinal ridge which formerly ran east and west through that part of the country, and which by some geological agency had since been superseded by the valley of the Weald. The Author had referred to the Chilgrove well, situated 4 miles north of Chichester. The Chichester Waterworks were constructed under Mr. Shelford's direction, and he was well acquainted with that part of the country and its geology. It would be seen from the geological map of the country from Worthing to Portsmouth that there was a tongue of clay land between those two points about 4 miles in width at Portsmouth, diminishing at Worthing to 1 mile. All along the southern side of that tongue of land the ground might be said to be alive with artesian springs, and there were also several waterworks. Worthing, immediately to the east of the tongue, was supplied from the Chalk. A little farther on to the west there was a spring of almost classical interest, near Littlehampton, and still farther on there were other springs, and at Chichester there were waterworks and an artesian well that overflowed. To the extreme west were the wells at Bedhampton, which supplied Portsmouth. The minimum water-line obtained at the upper end from the observations at Chilgrove, and at the other end from his own observations, after the drought of 1874, at the Chichester Waterworks, showed that the gradient referred to by Mr. Evans was 20 feet in a mile, nearly corresponding with what that gentleman had already stated. The Paper was principally based upon the observations and calculations which the Author had made with reference to the Chilgrove well. To maintain that minimum line, the Author stated that 3·29 inches of rainfall per annum were required to be absorbed, and that in seven years from 1853 to 1860 inclusive the depth of rain absorbed at Chilgrove exceeded 3·29 inches, but it was only half that amount in 1854. With a view to estimate the capacity of the district, putting aside the Lower Chalk, and dealing with the Upper, which was about 400 feet thick, and assuming that the waterworks' pumps could raise water from the 200 feet in Upper Chalk, he found by calculation that the whole outcrop of about 100 square miles of Upper Chalk would absorb 30,000,000 gallons per day on an average, and that there was storage capacity sufficient to last three years. Of course new maximum and new minimum water-lines would be formed under such circumstances, and local causes might operate to prevent the drainage to the pumps, and undoubtedly springs now artesian would become practically dry when the storage was utilised; but in that way only could he suppose that the popular notion of the vast storage capacity of the Chalk would be realised if the Author's observations and calculations were correct.

Mr. BALDWIN LATHAM said it would appear from the opinion expressed by the Author of the Paper that not more than four persons, in addition to himself, knew anything about the Chalk formation and its water-bearing characteristics, and of the four persons named, the result of their labours was summed up as "comparatively useless." The Author then claimed for his own statement "that is is not only the most complete, but also that it is the only correct account that has appeared" of the Chalk Water System. He felt proud, however, that the records of the Institution contained a vast amount of information on the subject, contributed by well-known scientific men.[1] He thought that the information conveyed in the Paper, combined with the desultory observations of the Author at various periods, were of very little value in judging of the water-bearing characteristics of the great Chalk formation. It was important, with regard to the water-line and the angle of friction, that the data should be absolutely correct. He had surveyed a large portion of the country in question to ascertain the direction of the flow of the water underground, the variation of its level at different periods, and the volume of water flowing off by the springs; and he had found that the levels taken by the Author, which were stated to be simply "approximate," were very different from the actual levels in the Chalk itself. He had measured fifty or sixty wells in common with the Author, and in none of them had the Author given the absolutely correct levels (*ante*, p. 112). During the past year he had measured considerably more than a hundred wells, most of them at least four times, at intervals of several weeks, the correct elevations of which had been taken and reduced to two places of decimals. He had placed upon the wall two sections (Plate 4*a*), one of the Caterham valley and the other of the Brighton Road valley. These sections showed four water-lines, or the height at which the water was found at the different periods of observation. With some slight exception in the first or uppermost line, all the lines were measured on the same day. He would not, however, now express any decided opinion upon the movement of the water in the Chalk, because the sections were taken upon the falling water, and he had reason to believe that if they had been taken when the water was rising the angles of friction would have been different. He made some observations ten years ago on the flow of water underground and the gaugings of wells. The gaugings of the springs at Croydon during the last year corroborated his former observations, and showed that the springs rose much more abruptly than they afterwards declined. Although he had made daily observations on some wells, and had ascertained the quantity of water flowing every week during the past year from the springs at Croydon, he still felt unable to form a decided opinion on many of the water-bearing properties of the Chalk formation; but when he had finished the series of observations, he hoped to lay the results of his labours before the members of the Institution. With reference to the friction of water in the soil, Professor Prestwich pointed out, in his work on the water-bearing strata of London (not quoted by the Author), that the water below the ground was subject to the same laws as water flowing above ground. But not a word was mentioned in the Paper about the movement of that great body of water in the Chalk, although that had a most important bearing on the water rising and falling in the wells. Water flowing through interstices, however small, or through a defined fissure, was subject to the same conditions as water flowing through any other channel, say a pipe. If a pipe 1 inch in diameter and 10,000 feet long, of uniform section throughout, in the first 1,000 feet received a volume of water equal to produce a velocity of 60 feet per minute, and in the second, and at every subsequent 1,000 feet an increment of water equal to the volume first received by the pipe, the velocity of flow in every 1,000 feet would be proportional to the numbers 1, 2, 3, 4, 5, &c., and the resistances to the flow as the numbers 1, 4, 9, 16, 25, &c., being as the squares of the velocities. Now, from the formula of Eytelwein, modified by James Leslie, and published by Beardmore, the discharge in cubic feet per minute from a circular pipe $= \frac{2{,}356 \sqrt{d^5}.}{\sqrt{\frac{l}{h}}}$ From this formula it followed that the first 1,000 feet of the 1-inch pipe would require an inclination of 1 in 207·2, and that every other section of the pipe must have a proportionately increased inclination to overcome the resistances due to the increasing velocity of flow occasioned by the reception of the additional volume of water at the assumed points. The inclination for each respective section would therefore be $\frac{207 \cdot 2}{1}$, $\frac{207 \cdot 2}{4}$, $\frac{207 \cdot 2}{9}$, $\frac{207 \cdot 2}{16}$, &c. These several inclinations, when united, formed approximately an ellipse. If a smaller duct were taken the resistances would be represented by a similar curve, but of greater convexity. Now the channels might either be of uniform size, or they might be increased in diameter with every additional volume of water, in which case the curve would be different. Assuming the same conditions as before, except that the pipe should be increased in size with every additional volume of water, so that throughout the whole length of the pipe the water moved with an equal velocity of 60 feet per minute. Since in the former case the first 1,000 feet of pipe would require an inclination of 1 in 207·2 in order to carry the necessary volume of water, and as with the same velocities the inclinations were in proportion to the multiples of the diameters of the ducts, the inclination of every section of the pipe would be as the numbers $207 \cdot 2 \times \sqrt{1}$, $207 \cdot 2 \times \sqrt{2}$, $207 \cdot 2 \times \sqrt{3}$, $207 \cdot 2 \times \sqrt{4}$, and so on. The several inclinations if plotted would represent a curve with the upper portion steep, but gradually diminishing proportionately as the inclinations were multiplied by the diameters of the respective channels. Supposing a given quantity of water were passed in at one end of a pipe or fissure of uniform bore, and that it flowed out at the other end, the resistances would be proportional to the length of the channel, and the resistance would be represented by a straight line. These curves and lines represented the angles of friction met with when water flowed through the strata of the earth. Another point referred to by the Author was that a given amount of rain, falling when the well was low, would not raise the water to the extent that an equal amount would raise it when it was at a higher level. That arose partly from the circumstance pointed out by Mr. Evans and Mr. Homersham with regard to the point of saturation. But it should also be remembered that the whole of the water stored in the Chalk was tending to run out at the same time; consequently, taking the well at a given depth, with sufficient rain falling into it to raise it 1 foot on a low head, it would produce a greater discharge than in the case of 1 foot of water at a high head, because the discharge was in proportion to the square root of the head. Take, for example, a reservoir with 1 foot head of water; this would cause a velocity of 8 feet per second, but a head of 16 feet would only give a velocity four times as great, so that 1 foot depth of water added to the top of a reservoir would produce a less discharge proportionately than 1 foot added at a lower level. There was, proportionately, more water running out of the Chalk with a given addition when the water was low than when the strata were charged and the wells were full. In ascertaining the direction of the flow of water, it was shown by all the sections, that where the water was flowing into a natural channel, the surface of the water in the channel receiving the water was convex. This was proved by the sections at the junction of the Caterham valley, which passed its underground waters into the Brighton Road valley. The section along the Brighton Road valley, at a point not quite 2 miles higher up than the junction with the Caterham valley, afforded an example of water flowing by an underground channel out of a valley, and at this point, Smithambottom, a line drawn from the surface of the water in the well, above the point of abstraction of the water, to the surface of the water in the first well below the point of abstraction showed a concavity of the water surface. Now he had ascertained that water did flow out of the main valley in this way, which took a north-westerly direction, so that in the case of abstraction of water from an underground channel the same laws were observed that governed the flow of water in defined channels.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vols. ii., ix., xiv., xx., and xlv.

By careful observation it was possible to determine absolutely every point where the water was admitted into a valley, and every point where it flowed out, and the direction of the flow could be ascertained. He had been led to look at the matter of the movement of underground water from a sanitary point of view, considering the immense importance of observing the movements of water in reference to its purity or pollution, so as to be able to select the best position for a well. Water in the earth followed, generally, the inclination of the surface, but not invariably, as was shown by the well at Harpsoak, where the water at one period of the year fell one way and at another period another way. No definite rule could be laid down. It had been asserted by the Author that the angle of friction increased as exhaustion proceeded; but ordinarily it was the reverse, for the point of overflow was fixed, and a straight line drawn from the highest water in the uppermost well to the point of natural overflow, represented the greatest angle of friction, and that angle as the water fell became less. The importance of hydrogeological surveys, from a sanitary point of view, might be seen from the position in which houses in the country were usually built; the house, facing down-hill so as to get an extensive view, and the well which furnished the supply of water being contiguous, and immediately behind the house; at the top of the garden, also behind the house, was the cesspool, and perhaps behind and above this a farmyard. In such an arrangement the sources of pollution were so placed that both the well and the house might be affected by the underground flow of water first carrying the impurities into the well, and then under the house. The picture he had drawn represented the general mode adopted in the arrangement of houses throughout the country. With a little knowledge of the subterranean movements of water it would be easy to convert many an unhealthy house into a perfectly healthy one, by simply moving the position of the well. In crowded localities no one could be safe in taking a water supply from a stratum which might be permeated with all the impurities flowing into it from the surface, or from a higher level. That water was affected in its purity to a considerable extent by the population of the contributing area was singularly borne out by the analysis of the water at Caterham Waterworks, at the head of the water area. Where there were but few houses within the drainage area, the water was pure; but down the valley the quality of the water was deteriorated by the great population which now inhabited it. As the population increased, in both the Caterham and Brighton Road valleys, in the absence of any system of sewerage for conveying away the waste products of animal life, and as all water used in these districts, together with all sorts of filth, was returned to cesspools sunk into the water-bearing strata, it was not difficult to conceive what must be the ultimate effect of this pernicious system, and that even now the water supply procured at times in some of the lower portions of the drainage area was not free from danger. Mr. Symons had made an admirable series of observations on the increase of temperature at various depths, and it had been ascertained that for every 50 or 55 feet in depth the water increased in temperature 1° Fahr. The most astounding thing was that in a comparatively deep well at Cambrian House, Caterham valley, the water had a lower temperature than it possessed when it got down to the shallow wells near Croydon. In the Godstone quarries the temperature of the water was 47°. Flowing out of the springs at Croydon, its temperature was 52°. He thought that the increase in temperature of the water observed in passing from the deep wells in the upper portion of the district to the shallow wells, was due to the angle of friction. The first law in thermo-dynamics was that heat was a source of mechanical power, and *vice versâ*. According to Joule's law, the mechanical equivalent of heat was equal to 772 foot-lbs., which would raise the temperature of 1 lb. of water from 50° to 51°. Here was water in motion through different points in the strata increasing in temperature from the deep to the shallow wells from 47° to 52°, or, taking the lower wells, from 49° to 52°. It was evident that there must be some reason for that increase beyond that of central heat. It held good at all periods of the year; also for the bourne which flowed in the winter of 1860 and spring of 1861. On that occasion the bourne burst from the ground at a temperature of 32°·8, and gradually attained a temperature of 45° at a lower point in the valley, by which time the water had increased to the maximum flow; but from this latter point, as the flow began to subside, the temperature declined to 42°·3, when the water disappeared under the earth. As it flowed out of the springs at Croydon, the temperature had again increased to 49°, that of the air in the shade at the time being 34°. Differences of temperature might be taken as an indication of movement. It would be seen by a minute examination of the sections, that where there were indications of water flowing into or out of a channel, or where the angle of resistance was raised, there was a corresponding alteration of temperature. It would be a matter of very great importance hereafter if an engineer, by observing increases of temperature, should be able to determine the direction of the flow of water, or the nature of the strata, and the resistance to the passage of water. It would be observed that the water-level at the Jolliffe Arms, in July, stood at 318 feet above the Ordnance datum; whereas at Harpsoak it stood at 318·5 feet, or 6 inches higher. The last observation showed that at Harpsoak the level was 302·1 feet above the Ordnance datum; whereas at the Jolliffe Arms it was 300·9 feet: also showing that the flow was in the same direction. It would be seen, however, that at the intermediate observations the level of the water at the Jolliffe Arms was higher than at Harpsoak; so that the water flowed in the opposite direction at one time to what it did at another. The section of the Caterham valley, which showed the water-line when a bourne was flowing, was of peculiar value, as it threw light upon the phenomena of a bourne. If, on the section of the position in which the bourne flowed in the Caterham valley in the spring of 1876, a straight line were drawn from the surface of the water in the first well above the bourne to the surface of the water in a well below, it would exactly coincide with the surface of the water as it flowed as a bourne, so that the observation made by the Author, that bournes were due simply to the elevation of the water in the Chalk, was correct. Many other points might be mentioned with regard to the flow of bournes. The height to which water had risen in the Godstone quarries in the year 1853 was 467·5 feet above the Ordnance datum, as shown in the annexed table (page 133). This was a year when there was a great bourne; during the present year, when there was a small bourne, the water had risen to 443·12 feet. The bourne in 1876 broke out near the Rose and Crown, under Riddlesdown, and after flowing about 1 mile disappeared below the surface. Reference had been made to the bourne flowing out of the Merstham tunnel. This bourne had also flowed during last spring, and had disappeared in the gravel near the Red Lion at Smithambottom. The water-line in the Chalk at that point was at that time a long way below the surface. Had it been one of the great bourne years, like 1853 or 1866, no doubt the whole water-line shown below the surface would have been considerably elevated, and in consequence the bourne would have been more copious, and would have flowed for a longer time. He was of opinion that satisfactory calculations, based upon the rainfall, could not at the present time be made of the amount of water likely to be yielded by the Chalk. A few months ago a discussion took place at the Institution, when Dr. Gilbert put in a number of records which showed that with deeper

HEIGHT to which WATER has RISEN in the GODSTONE STONE QUARRIES (UPPER GREENSAND) in EACH YEAR, and DATE of the MAXIMUM WATER-LEVEL.

Year.	Month.	Day of the Month of Highest Water.	Height which Water rose in the Quarries above Ordnance Datum.	Remarks.
			Feet.	
1843	June .	28	456·19	
1844	May. .	2	465·35	
1845	April .	15	452·13	
1846	March .	18	459·56	
1847	„ .	19	456·91	
1848	May. .	18	461·39	
1849	March .	19	466·09	
1850	June .	7	451·90	
1851	May. .	12	458·25	
1852	Nov. .	26	461·87	Flow of Bourne.
1853	Jan.. .	31	467·45	Copious flow of Bourne.
1854	Feb.. .	10	462·75	
1855	March .	6	439·31	
1856	May. .	2	443·36	
1857	March .	10	450·01	
1859	Dec.. .	30	446·32	
1860	July. .	23	455·41	Moderate flow of Bourne in Caterham valley. Commenced to flow November 1860, and was flowing in February 1861.
1861	April .	3	465·00	
1862	May. .	29	456·02	
1863	March .	4	452·80	
1864	April .	16	437·85	
1865	Feb.. .	14	438·22	
1866	March .	17	462·31	Copious flow of Bourne.
1867	April .	20	454·96	
1873	„ .	1	452·89	Moderate flow of Bourne which reached Croydon.
1874	May. .	4	436·81	
1875	April .	12	436·81	
1876	„ .	20	443·12	Small Bourne in Caterham valley.

gauges the amount of percolation was considerably less than had been found with shallow gauges. That might be true of Chalk. Nothing was at present known, except with regard to a mere film of surface, as to the amount of percolation which might take place.

There could be no doubt that very little of the large quantity of water which fell found its way to the chalk springs. He might mention that on the 23rd of April in the present year the springs at Croydon reached their maximum discharge, and since that period they had been gradually declining. During the last four days upwards of 1¾ inch of rain had fallen at Croydon, yet a measurement that had been made that day showed an increase of only 1 inch in depth in a well in which the water-level had subsided from 166·31 feet above Ordnance datum on the 31st of May, 1876, to 157·61 feet above Ordnance datum on the 4th of December, 1876. With reference to the Chilgrove well, the Author stated that "by calculation" a rainfall of 2·9 inches raised the water from 40 to 98 feet in depth. He did not know what was meant by the words "by calculation." It was usual to deal with absolute facts. It would be observed that 2·9 inches of actual rainfall, or percolation, were said to have raised the water in the well 58 feet; but it was found, by an elaborate calculation of the Author, that 3·29 inches were necessary to maintain it at 5 feet from the bottom of the same well. If 2·9 inches gave a yield of water that would raise the well to a height of 58 feet, surely 3·29 inches ought to raise it higher than 5 feet. The height to which the water had risen in the Upper Greensand stone quarries at Godstone was shown in the preceding table; it would be noticed that the records were missing for the year 1858, which was an exceptionally dry year. From the inquiries he had made, it appeared that the springs were so low in that particular year, that it was doubtful if the water had entered the quarries at all. The observations had been made by an old man named Hill, who had worked in the quarries for many years, and who had every year marked on the wall of the quarry the point to which the water rose, together with the date when the water reached its maximum height; and from these data he had been able to take the levels and compare the heights with Ordnance datum.

Dr. SIEMENS said an observation had fallen from Mr. Baldwin Latham which, he thought, ought not to pass unchallenged—that the water flowing from deep wells was warmer than that flowing from shallow wells, and that the increase in temperature in it might be attributed to the greater friction of the water through the Chalk Formation. Mr. Latham had correctly given the coefficient of increase, 1° for every 772 feet of water percolating downwards; but Mr. Latham had apparently not considered the fact that this difference of level did not include the depth of the water in the well, but only the depth from the surface, where the rain fell to the level of the water in the well, because the depth of water in the well balanced so much of the hydrostatic pressure as would urge the water through the Chalk, and therefore did not add to the accelerated force, or the force to be developed into heat by friction. It was therefore necessary to consider what was the difference of level between the water in the well, and the level where the rain fell and sank down into the ground; and there could be no doubt that that amount of hydrostatic pressure was lost, and therefore converted into heat. But would that heat appear as temperature in the water? He doubted it very much, because before the well was pumped the Chalk was filled with water, and that water was in static equilibrium. It was only when the well was worked that the water would flow and friction be generated. That amount of friction would not only heat the water, but it had to heat the stratum of chalk before it could be sensible to a thermometer, and considering the enormous mass of material which would thus have to be heated by a comparatively small amount of water, Dr. Siemens thought the idea of heat being derived from mechanical friction in the chalk must be dismissed. Mr. Latham's observations seemed almost to imply that he attributed heat-engendering power to the horizontal distance traversed by the water; and it therefore should be clearly understood that the amount of heat engendered by friction could in no case exceed the equivalent head of water, or accelerating force expended; or, in other words, the 772 feet difference of level was necessary to produce as much heat as would raise the temperature of water percolating through narrow passages 1° Fahr. Another explanation, that of the depth to which the water might dip on its way to the well, appeared to him to account much better for the difference of temperature in different levels in the Chalk. Of course, if the water dipped to a very great depth and afterwards rose again, the dip would not be productive of heat by friction, inasmuch as the available heat for friction was due to the difference of final levels, but it might give rise to an increase of temperature owing to the warmer strata which the water had touched on its way.

Mr. Latham said that the temperature in deep wells at the top of the district was lower than in shallower wells lower down. The water was moving from the deep wells to the shallow ones.

Mr. E. Easton said that any facts that were brought before the Institution to throw light upon such an important subject could only be received with gratitude; but, in common with Mr. Latham, he wished the Author had put his information in a form which would have been a little more applicable to the wants of hydraulic engineers. He wanted, in common with other members of the profession, to get water out of the Chalk, and he wished that Mr. Lucas had taken into account, as well as the wells which were not drawn upon, the wells that were affected by pumping operations. The stratum was invariably more or less drawn upon by springs, just as, artificially, it was drawn upon by pumping operations. The springs issued at a certain level and discharged either into rivers at a considerable elevation above the sea, or into rivers at a level with the sea, or into the sea itself. One instance was the system which emptied itself at Carshalton, Croydon, and Beddington, in springs at about 100 feet above the sea. At Grays, and at other places below London, the water was delivered in large quantities into the Thames, under the sea-level midway between high water and low water; and at the sea-coast the same thing took place at Brighton, Lewes, Ramsgate, and wherever the chalk cliffs abutted upon the sea. Any investigation of the subject, therefore, should take into account the fact that at all times a large quantity of water was passing through the fissures in a natural way. If the Author had taken that into consideration he would not have been led into one or two conclusions with which he could not, after an experience of many years, agree. The Author stated in the Appendix as a remarkable fact, and it would have been remarkable if it had been a fact, that the inclination of the water in the Chalk was greater when the water was at its minimum than when it was at its maximum. That might be so here and there locally, but from what was known of the flow of water through the fissures and channels of the Chalk it was, as a rule, an impossibility. He had a section of Caterham valley, taken very carefully for him in 1866 for the purpose of ascertaining something as to the flow of water in the Chalk, when the bourne was in operation. The bourne was running very copiously indeed; there had been a considerable rainfall (33 inches) the year before, and two other wet years previously. The depths of the wells were taken on the same day, the 23rd of March. They were observed again on the 17th of August in the same year. The result was as might have been expected. When there was less water to be delivered through the fissures and channels the hydraulic gradient was less than it was when there was a larger quantity to be delivered. At the upper end where it broke out into springs at Titsey, the same elevation or hump occurred at the summit which Mr. Latham had shown (Plate 4*a*). The bourne ran down towards Godstone. Unless questions of that kind were looked at on general principles an erroneous conclusion might be arrived at, such as had been deduced by the Author, that the minimum water-line might have the greatest gradient. No doubt if observations of other wells could have been continued on to the Titsey springs, somewhere or other a steeper gradient would have been found for a short distance. The behaviour of water in relation to the rainfall, as bearing upon the locality in question, was a matter of great importance. He had compared the height of the water of the wells at the Lewes Road Waterworks at Brighton with the rainfall in each year, and at certain intervals of three or four months the water-line in the wells invariably followed that of the rainfall. The valley of the Lewes Road was similar in its character to the Caterham valley. It emptied into the sea, and the water-line rose in a uniform gradient till it reached Clayton tunnel, at which point it was 250 feet above the sea. The average gradient was 40 feet per mile: the gradient at the Caterham valley when the bourne was out was 37½ feet per mile, and on the 17th of August, 1866, was 29 feet per mile. In the case of the Lewes Road Waterworks all the water which fell upon the Chalk was absorbed by the Chalk or evaporated from it. He could not agree with what had been said by Mr. Evans as to the amount absorbed per annum by the Chalk being from 4 to 6 inches; or how, at Brighton, such a quantity of water was obtained out of the Chalk, if there was not a great deal more going into it. He thought that both Mr. Evans and Professor Ansted had lost sight of a material fact in considering the amount of water that could be absorbed into denuded chalk, namely, that from the surface of the Chalk a very considerable amount of water was taken absolutely out of the atmosphere at certain times of the year when the rain-gauge showed no increase whatever. Even when there was no rainfall water was condensed from the atmosphere by a cold surface and fell upon that surface; and if it was a pond it increased the depth, and in the case of chalk or earth the moisture was absorbed into it. In no other way could he account for the persistence with which the ponds on the surface of the Downs—not only near Brighton, but on Salisbury Plain, and other places—maintained their height, although they were drawn upon by cattle. At the commencement of the investigations on evaporation by Mr. Symons and Mr. Griffith, they were astonished on one very hot day to find that instead of the gauge showing a loss of water, there was an absolute gain: which gain had been absorbed from the atmosphere. That fact, which was sometimes lost sight of, would account for the great capacity of the Chalk for absorbing, storing, and giving out water.

He totally disagreed with the conclusions of the Author, at which he would probably never have arrived if he had had a sufficient amount of experience of the results of pumping. His remark as to the "film of rain," and the amount represented in the depth of wells, was a fallacy. A consideration of the sections would show that the one hundred and twenty times was simply taken at one particular point—probably the highest point in the system. It varied all the way down the line of section until it came perhaps to only ten or twelve times the depth of the rain. At Brighton at the Goldstone Bottom works there was never a variation of more than 6 or 8 feet.

The real fact as to the quantity of water to be got from the Chalk, he supposed, was this: that just as in the gathering ground of a great river one could calculate the amount that fell upon the surface available for collection into the reservoir; so in the Chalk the amount of water which did not go off in surface streams or by evaporation was absorbed, and was available if it could only be got at. The means generally resorted to by hydraulic engineers were wells and tunnels; but he did not agree with the Author that borings should not be resorted to, because there were often chasms and reservoirs in the Chalk. Layers of flints kept the water down, and when these were pierced, the water came through them. The way in which the water was to be got out of the Chalk would vary with the particular locality. One remark of Professor Ansted had startled him very much, because it was totally at variance with the results of all his practical experience—that the evaporation from the Chalk (chalk being a sponge) was so great that it would ultimately dry the very bottom stratum. But the very fact of the Chalk being a sponge militated against that idea. If it was a sponge the absorption, as well as the evaporation, would go on; and it came back to the point, that the measure of the amount of water to be got out of the Chalk was the amount which was absorbed into it.

At the excavations at Brighton along the horizontal tunnels there could be traced a layer of flints less than an inch in thickness, for a length of 150 or 200 feet. It was a floor of flints in the interstices between the masses of chalk, and under those flints water was frequently found in the way he had described. At Lewes, he had occasion, two years ago—in consequence of an epidemic, and of the Government inspector thinking that some of the water in the chalk springs was drawn from the river at high tides—to bore a hole and get the water independently of those springs. In so doing layers of flints were struck, and the water supply was increased nearly in proportion to the depths to which the borings went. That had also been the case with regard to the borings of Mr. Homersham at Canterbury. He mentioned the matter only to point out that although the usual way in which an engineer would endeavour to get water from the Chalk near the sea would be by driving tunnels or adits parallel to the sea to get over the fissures, it by no means followed that in many situations it would not be found that boring would be equally or more efficient. Therefore, in dealing with so large a question as the Chalk Water System, it was necessary to look widely over the whole of that system before drawing conclusions which, when published in the annals of the Institution, might mislead future engineers and others, owing to false deductions being made from the premises. The conclusion at which he arrived, from an experience of twenty years, was that in the Chalk, undenuded of gravel and clay (the pure Chalk System not covered by anything which intercepted the rainfall), the water usually found its way through the crevices and channels described by the Author; and in that case, the only way of getting the water out effectually was by driving lateral adits at a given level. It was often found, especially where the Chalk had been covered by gravel and clay, and where these strata had been uplifted and disturbed, that the water accumulated in large reservoirs and chasms, and that it could be tapped by boring instead of by a tunnel. He had already referred to a remark made by the Author as to the minimum and maximum water-line in the Chalk, and had pointed out that, as a rule, the hydraulic mean gradient of the water in the Chalk when it was saturated was greater than when it had a less quantity of water in it. The conclusion of the Author as to the small quantity that could be obtained out of the Chalk was, he thought, a wrong conclusion from his own premises. The very fact that the water rose and fell in the way described, and shown in the sections, proved that there was a very large quantity of water in the Chalk, and that as a water-bearing stratum it was one of the most valuable in the world. Nothing more than a consideration of well-known facts was needed to show that that was the case. When it was remembered that of the whole volume of the Thames running over Teddington Lock in a dry season, when the springs were low, one-third was derived from the Chalk, and that two-thirds of the remaining quantity pumped into London also came from the Chalk almost directly, it could not be said that it was a stratum that did not give a very considerable quantity of water. There was abundant direct testimony as to the number of gallons actually pumped into London from the Chalk System. During the last hundred years it had been the practice, when water was required in the centre of London, to bore down to the Chalk, and it was obtained in considerable quantities. He had endeavoured to make a rough estimate of the quantity of water pumped out of the Chalk, and the strata overlying it, in London itself, and taking first a radius of 1 mile from Charing Cross, then another radius of 1 mile, and so on, about 1,000,000 gallons a day could be pumped out of the Chalk from each, and was actually pumped out in the driest seasons; so that within 6 or 7 miles from Charing Cross there was a supply of 6,000,000 or 7,000,000 gallons daily. That was of course much less in proportion than the quantity of water that could be obtained out of the Chalk, when not covered by the Tertiaries. Going below London, and away from the operation of the springs, the Kent Company pumped 11,000,000 gallons daily. Then the copious springs running into the river at Grays and all along the Essex and Kent coasts, tended to show that there was a very large quantity of water in the Chalk. That was only what might be expected from the large area of chalk both denuded and covered. The only point of difference between himself and those who stated that the Chalk did not yield much water, was as to the question of the absorption of the rain. He was satisfied that if experiments could be made on a large scale, it would be found that very much more water was absorbed into the Chalk than had ever yet been estimated or accounted for. He was astonished at the remark of Mr. Baldwin Latham as to the difference of temperature in the water at Godstone and Caterham, and still more astonished at the deductions which he had drawn. With regard to the fact itself, he thought there must be some mistake. He had been favoured by Mr. Homersham with a statement of the present temperature in the Godstone quarries, which he found to be about 52°, so that he thought there must have been some circumstances that interfered with the test when Mr. Latham had taken it.

Mr. Edwin Chadwick observed that the Author had the laudable ambition of founding a new system of hydrology, but such a system would for engineering include an examination of the qualities of water obtainable from different strata, to determine the values of searches for it, a topic which had not been touched upon in the Paper. On the quality the whole question mainly turned, and upon it he had to make what would appear to be something like a retractation. Mr. Homersham had blamed him for having, when in office, set aside the near chalk water supplies for the metropolis. But he held now as then, that the softest water was the most eligible for the supply of a population, and the subsequent course of sanitation had fully confirmed that opinion. A grain or two of hardness a day was of no great consequence, but a few grains daily for a year might be, and for every gain of a grain in softness it would be found worth while sanitarily to go somewhat farther afield. The circumstances of the time were these. He entered very fully into the examination of Dr. Clark's process. Dr. Clark came to his house to show what he could do with the domestic water supply. But he did not then appear to succeed in reducing the hardness much below 8°, the point obtained by boiling. Now there were then ascertained, by a close search, to be in the Surrey sands perennial springs yielding some forty millions of gallons of water daily (or double the then actual consumption of the metropolis) of about 3° or 4° of hardness. Between supplies of such a quality, and the supplies of the quality then obtainable from the Chalk, there could be no impartial difficulty of choice. Now, however, by an improvement in the application of Clark's process, it was declared that chalk water was got down to about 2° of hardness. A water of such a quality might compete even with the perennial spring water of 3° or 4° of hardness. Mr. Bateman had told him that the chalk water at Bushey was got down to about 2° of hardness, and that it was so brilliant, so potable and excellent, that he almost admitted that it competed with the Loch Katrine water, which was under 2° of hardness. Dr. Frankland considered that the softened Bushey chalk water was of a better quality even than the Loch Katrine water. And so it might be, for this reason, that such lake water was in times of flood impregnated with peat, which, though not injurious, was not agreeable. If, then, at an inconsiderable expense for softening, water of such a high quality could be obtained near, why go several hundred miles off for a lake-water supply? The improved process would, no doubt, be of immense relief and benefit to the Chalk districts, and upon the testimony he had received, he felt bound to come forward and say so. What had been determined, in principle, at that time was the abandonment of river supplies for spring supplies wherever spring supplies could be got; of river supplies because, though sewage could and ought to be diverted from them as a waste of manure, the surface washings of cultivated and manured lands could not be diverted, and impurities were absorbed which no subsequent filtration sufficiently removed, as continued experience showed;—of spring supplies, pure at the source, as needing no filtration. The quality and value of a potable water were determined, not by the sensations of the robust, the coarse, and the heedless, but by those of the weakly, the sickly and by the effects on children. Hence softness was to be carefully sought for hospitals. A chalk water supply had been got in Kent and carefully softened by Clark's process, for the great Herbert Hospital, where it was pronounced to be a success. Soft water, which was of high value for its solubility, for digestion, needed, however, precautions in distribution, on account of its high solvent and absorptive power of any substances—of floating spores or gaseous matters. His son, who was Engineer-in-Chief of the New Waterworks at Odessa, where the supply was the softest of any known for a large population, informed him that this absorptive quality was peculiarly manifested in this,—that water standing in a bottle twelve hours showed a green scum, and was unfitted for use. It followed from such experience, that the more water was softened the more important it was to adopt the principle early laid down, and now becoming prevalent, of constant and direct distribution, fresh—with the original rural aeration, and without stagnant detention, exposure, or deaeration. Such research as the Paper displayed into the water-bearing power of the Chalk strata would be of value in diminishing the great risk and expense of deep well-sinking, which, in his observation, had not succeeded in more than one case out of three or four. The Author of the Paper, in stating that his work began where the work of the late Sir Henry de la Beche in the Geological Survey ended, did injustice to Sir Henry, who was well informed, not only on the solid stratification examined, but on the water-bearing power of the stratification examined, and of much of the quality, as well as the general quantity, of the water derivable from it. The Ordnance Geological Survey Department had more information on the subject than might be found in published reports, and, he was authorized to state, readily imparted it for the service of civil engineers who were conducting examinations for works.

Mr. LONGRIDGE said that he did not rise to criticise the Author's conclusions, for he was not sufficiently acquainted with the details of the subject, but he was struck with the great difference of opinion still existing, not only with regard to the extent of water in the Chalk System, but to the conditions under which it existed. Mr. Clutterbuck, for instance, who had devoted a great amount of time to the subject, had stated that water would not pass through chalk, but that it passed through the crevices and fissures; and Mr. Baldwin Latham maintained that the passage of water through the Chalk was analogous to the passage of water through pipes, and that the same hydraulic formula was applicable to both. Professor Ansted stated that, although there was a great abundance of water in the Chalk, it was not available. He thought, however, that in the records of the Institution there was evidence not only of an enormous supply of water in the Chalk, but that very large quantities had been got out of it; and that the passage of the water was through the Chalk itself, and not confined to the crevices. Indeed, were it confined to the crevices and fissures, they would very soon get emptied. There was evidence that ten and a half or eleven million gallons had been pumped out from an area of 150 square miles every day, for the last ten or fifteen years, without diminishing the supply. That at first staggered him considerably, but on further reflection he did not think that there was great cause for surprise. Professor Ansted, many years ago, showed that every cubic foot of the Upper Chalk, when dried, would absorb 2½ gallons of water, and that every cubic foot of the Lower Chalk would absorb 2 gallons of water.[1] Two and a half gallons amounted to 40 per cent. of the bulk of a cubic foot, and 2 gallons to 33 per cent. Pores equal to 40 per cent. of the bulk would in the aggregate be equal to a 9-inch pipe on every side of the cube. When it was remembered that every square foot of chalk exposed in a well presented a surface equal to that of a 9-inch pipe, it was no wonder that a large quantity of water could be obtained, if it could permeate through the Chalk. The question was, could it be so got through? Whatever might be the exact constitution of the Chalk, it was certainly not a series of tubes, and he would therefore put aside at once Mr. Baldwin Latham's idea, that any hydraulic formula of the description he had mentioned could be applicable; it was impossible to get the mean hydraulic radius, and therefore impossible to apply the calculation for a pipe to the Chalk. But it was well known, that with a certain pressure of water at the top of a capillary tube, however small, a certain amount of water could be got through. The full amount due to the head could not of course be obtained, because the capillary attraction was very great indeed when the capillary tube was small. Now, although a mass of chalk was not a mass of capillary tubes, the action was analogous; it was a mass of interstices like a huge sponge, and the adhesion of the walls of the interstices to the water was so great that it required considerable pressure for the water to percolate. But taking a piece of chalk, and bringing a pressure of water on the top, it would be found that the water would trickle through, as through a sponge. Taking the case of a well sunk into the Chalk below the water-line, the mass of chalk would be, he maintained, more or less saturated with water. Towards the top, in the dry season, the water partly evaporated. He could not follow Professor Ansted in his idea that the water would evaporate to a great depth. It was a question as to the depth at which the attraction of the atmosphere for the water would balance the capillary attraction of the Chalk for the water. Below that point the Chalk would be more or less saturated, till what had been called the water-line, A B (Fig. 1), was reached, which water-line ran pretty nearly to the outcrop. He maintained that it was a mistake to call it absolutely the water-line, because there was as much water in a cubic foot of chalk immediately above as in a cubic foot immediately below; that, however, was the line at which the capillary attraction and the resistance equally balanced the hydrostatic pressure. Consequently above that line the Chalk would yield water, and below it would not. Supposing a well, C D, to be sunk in the Chalk, and the water to be pumped out was level, E, every foot below the water-line gave an open surface equal to a 9-inch pipe, and taking a well of 8 feet in diameter, it would be equal to twenty-five 9-inch pipes for each foot in depth. The pressure of the water, at the velocity at which it was flowing, exactly counterbalanced the resistance of the capillarity and the friction through the pores of the Chalk; and as long as the pumping went on at the rate at which this balance continued, the level still remained the same; but if, in consequence of heavy rain, the line of saturation rose, say to ½ inch above the other, what would be the result? There was a pressure or a fall, A F, which, for example, call 81

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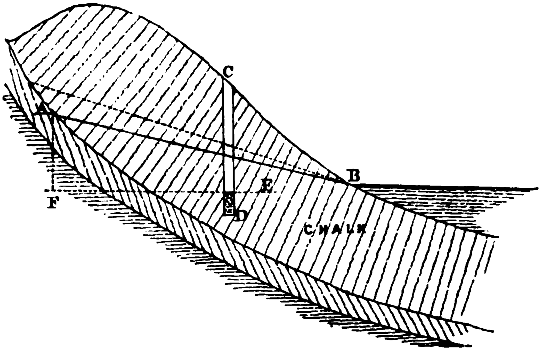
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 368.

Fig. 1.



feet in the first case, and of 81 feet ½ inch in the second case. That would make a difference of velocity due to pressure of about 1⅓ foot per minute. Consequently, over every one of the 9-inch pipes there was a velocity of 1⅓ foot multiplied by the area. The result would be that, in a well of that dimension, with a rise of ½ inch in the water-line, there would be a rise in the well equal to 2 feet per minute. Of course, actually, there was never such a rise as that, because there was never a sudden rise of ½ inch in the water-line; but that showed distinctly how a small rise in the water-line might occasion a rapid rise in the well if the water did absolutely pass through the Chalk; and he did not see how it could be otherwise, if the hydrostatic pressure upon it was increased. No doubt, however, the water came much more quickly through the crevices, but these crevices were, in his opinion, fed from the solid chalk through its pores. He saw no reason to doubt Mr. Homersham's statement as to the quantity of water that could be pumped through the Chalk. According to the experiments of Professor Ansted, each cubic foot of chalk would contain from 2 to 2½ gallons of water, equal to 250,000 tons per square mile for each foot in depth; and taking the depth of the Chalk at 100 feet, it would amount to 25,000,000 tons per square mile for each foot in depth, or 3,750,000,000 tons for 150 square miles. The quantity pumped out was 50,000 tons a day; consequently, if there was no supply going into the Chalk, and no outflow by springs, it would take about two hundred years to pump it all out. There was plenty of room in the Chalk for the water, plenty of area in the pores for it to pass through, and he saw no reason why it should not do so, or why any alarm should be felt as to exhausting the Chalk by pumping operations. Taking the population of London at 3,500,000, 30 gallons per day would require 171,550,000 tons per annum, and assuming a 6-inch absorption per annum, or 384,000 tons per square mile, there would be required an absorbent area of 447 square miles; or, supposing half the water ran to waste, an area of about 900 square miles to supply London with 30 gallons per head per day. He believed that that was about the area stated by the Rivers Pollution Commission to be available for the supply of London. With regard to the question of absorption, he would take the opportunity of making a few observations which he had intended to offer on the occasion of the discussion on another Paper in March last. He did not place much reliance upon the experiments made by Mr. Greaves's percolation gauges. In the first place the soil was artificial, and as such could only give the results of a similar soil under similar circumstances. Then the conditions were utterly dissimilar to those existing in nature. In the gauge there was a definite area of soil of a certain thickness, and a hollow space below into which the water which percolated passed. In nature the subsoil was more or less permeable by water, and the permeability depended upon its state of saturation, and was further affected by the extent to which artificial drainage had been carried out. Again, the ratio of evaporation to percolation depended on a great variety of circumstances, to wit, the nature of the surface and subsoil, the nature and growth of the vegetation, the prevailing wind, the electrical condition of the atmosphere, the mean annual temperature, and the combined effect of maximum temperature on the movement of the atmosphere. Moreover, it was an established fact that earth highly charged with water gave rise to rapid evaporation, but as it became drier it retained the moisture with great force.

Then again the depth to which water would penetrate subsoil depended greatly on the rate at which it fell; for instance, it was observed on one occasion that in the month of June, in the Bourbonnois, a rainfall of 3·02 inches in eighty-four minutes only penetrated into the soil to a depth of 2 inches, whilst a fine rain in the month of July, which gave only a depth of 1·04 inch in seven hours, penetrated the same soil to a depth of 4·4 inches.[1]

Indeed, it was difficult to see what practical use could be made of the experiments recorded by Mr. Greaves, seeing the immense difference between the percolation through sand and through earth as shown in his table of averages of fourteen years, for a rainfall of 25·7 inches, viz.:—

	Sand.	Earth.
Evaporation . . .	4·30 inches.	18·20 inches.
Percolation . . .	21·40 „	7·50 „
	25·70 „	25·70 „

It was very evident that the enormous difference between what was called sand and earth rendered these observations of very little general utility. He was of opinion that the only really valuable results, and then only of local value, were those derived from the actual quantity of water flowing off a given watershed by the rivers and brooks, and measured by actual gauging.

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[1] Pareto, "Traité de l'Emploi des Eaux en Agriculture," vol. i., p. 199.

Being engaged professionally as consulting engineer in an extensive project for reclaiming land on the delta of the Po, near Ferrara, where there was no outfall, and where, consequently, he had to determine the pumping power requisite to keep a large area free from water, it became his duty to ascertain what proportion of the rainfall required to be pumped. There was a reclaimed area in the same district known by the name of the Consorzio Dossi Vallieri, similarly situated to the larger reclamation with which he had to do, and on visiting the pumping establishment in 1871, he was allowed to take an extract from the registers of the company for the ten years 1859 to 1869. The rainfall had been carefully registered by rain-gauges placed at different parts of the estate, and the quantity pumped off was registered by gauging the outfall from the scoop-wheel, which was a rectangular channel of masonry. The records appeared to have been kept with care, and might be taken as substantially correct. The total area drained was about 10,500 acres. The whole of the drainage water was pumped, there being no other outfall. The average annual rainfall for the ten years was 28·5 inches, while the average annual quantity of water pumped was equal to a depth over the area of 10·4 inches. Consequently the proportion pumped was 36½ per cent. of the rainfall. In this case the whole of the land was in tillage, growing very fine crops of wheat, Indian corn, and hemp.

In the case of the reclamation in which he was at present professionally engaged, the area drained was about 125,000 acres, and the whole of this drainage was effected by the engines supplied by Messrs. J. and H. Gwynne, of Hammersmith.

The depth of rainfall and snow over the area during the first twelve months of operation was	24·016 inches.
The quantity of water pumped during the same period was equal to	5·945 ,,

Consequently 27·55 per cent. was pumped, leaving 72·45 per cent. as having been evaporated. This was less than the drainage of the ten years first mentioned, and might perhaps be accounted for by last year being one of exceptional dryness, and the rainfall below the average. The two districts were contiguous to each other. He had just received an account of the second year's operations. The year had been an extremely wet one, the rainfall from July 1, 1875, to June 30, 1876, having been 41·025 inches, being 45 per cent. above the average, giving a total quantity of water falling upon the surface of 18,394,338,600 cubic feet, of which 37 per cent. had been pumped off. Of this, however, about 5 per cent. of the rainfall fell on the surface of the drains and canals, and 95 per cent. actually percolated and afterwards found its way into the drainage system and was pumped off. This reduced the actual percolation to about 33 per cent. of the rainfall on the absorbing surface.

He thought that a collection of such facts and the gauging of the streams of various drainage areas would be much more reliable than deductions from experiments made with artificial percolation gauges.

Mr. J. GRANT said that Clark's process was in use some years ago at the Plumstead waterworks, Woolwich, and it would be interesting to know why it was abandoned; whether it was too costly, or whether it was found inconvenient in practice to supply one part of the district with soft water and another part with hard.

Mr. HOMERSHAM observed that the process was never abandoned while the works were in the hands of the Plumpstead Company, which constructed the works. An explanation of that subject had been given in his evidence before the Royal Commission on Water Supply in March 1868. When the Plumpstead works were sold to the Kent Company they ceased to work the process, to the great dissatisfaction of the consumers, but since that time he had constructed works for the Government, at Shooters Hill, to soften the water supplied by the Kent Company for the use of the Herbert Hospital.

Professor WANKLYN said he could give an explanation why the Clark process could not be applicable to the Kent water. It was capable of removing carbonate of lime from water, and nothing else. All lime that was present in the state of sulphate, or chloride, or any other condition except carbonate, was not removed by the process. Magnesia was not removed by it; and the water supplied by the Kent Company contained so much lime and magnesia in states other than carbonate, that after the application of the Clark process it had 7° or 8° of hardness. There was a very simple rule by which the efficacy of the process upon a given sample of water could be determined. By making an analysis, and ascertaining how much lime and magnesia were present in states other than carbonate, the extent of the softening could be deduced. It had been stated that water, from being very hard, had been softened by the Clark process until it had only 2° of hardness; but there were very few waters that could be softened to that extent. He had never met with a natural water which could be so softened. If there was a little magnesia in the water it should be remembered that the solubility of carbonate of magnesia was much greater than that of carbonate of lime, so that the magnesia would have to be allowed for. The determinations of the hardness of water were rather uncertain in the presence of magnesia, and he believed, therefore, that the statement that the water in question was softened to 2° by the Clark process must have depended upon the hardness being improperly taken. There being some magnesia in the water, the determination of the total hardness was somewhat difficult. The hardness, however, after softening, would be 7°; and he knew no application of Clark's process that would get it lower.

Mr. Cowper contended that when members had taken the trouble to ascertain facts, whether for their own private purpose or for public use, he thought it was their duty to bring them forward if they bore upon any subject under discussion. He had ascertained that a cubic foot of chalk weighed, when wet (not dripping), 118 lbs., and when dry 94 lbs.; so that there was room for 24 lbs. of water in every cubic foot of chalk. Considering the enormous amount of chalk existing in those districts where water was obtained from it, that fact was a useful and important one. He regarded the Chalk as a sponge, which, if it was rather more full at one time than another, was practically an enormous reservoir of water to a large extent available. He did not say that all the water that chalk held could be got out of it; but a great deal of it could be obtained from it after a wet season. Another fact he had ascertained had reference to the statement that solid chalk was impermeable. He had picked out the most solid piece of the Upper Chalk that he could find, 2 inches thick, without any fissure or crack, and had passed water through it at the rate of 2 lbs. per hour for every square foot of surface continuously and regularly. Taking a piece of chalk 200 feet thick, with a head of 478 feet of water, and allowing for an increased area for the water to permeate, as the distance from the point where the water was taken was increased, it would pass through every square foot at about the same rate; but in the case of a well there would only be a head equal to the thickness of the Chalk, and then the rate would not be so great. He agreed with the observation of Mr. Easton, that if the hydraulic head or the inclination of the surface of the flowing water was increased, the Chalk having so large a capacity could take up much more, and give out much more according as the season was wet or dry.

Mr. Symons said he could not agree with the statement of the

Author that the meteorologists should abandon the subject where the hydrogeologists took it up. Shortly after making that assertion, the Author had plunged into the subject of evaporation, and if that was not a meteorological phenomenon he did not know what was. The Author had not done much with respect to the question of rainfall, and what he had done he had tried to do too well. He had compared some observations in the neighbourhood of Dorking with those made at Croydon. If he had taken identical years at the different stations, he would have obtained approximately accurate results; but he had selected a long series of years at Greenwich, and by including some exceptional years he computed that the Denbies had the enormous excess over Croydon of 37½ per cent. If he would discard the Greenwich observations, and work simply with the two stations, he would find that 27½ per cent. was nearer the mark.[1] With regard to percolation, he agreed that it was lamentable that, after thirty or forty years' work, there should be nothing but a mass of contradictions. There was, indeed, little else in the discussion on the present Paper. The Author started at Chilgrove with a rainfall of 32 inches, of which he said 6½ inches were available for subterranean supply, showing the tremendous loss of 25½ inches. He did not profess to be an engineer, but his impression was that there were very few districts where there was anything approaching such a loss. Professor Ansted went further, and said he believed that the evaporation might equal the entire rainfall. If so, how was it possible to account for the volumes of water in the Chalk? At Grays any one might see almost rivers of water running through the Chalk; and to say that the evaporation from the Chalk was equal to the rainfall upon it was, he thought, a self-evident absurdity. The Author had referred to the wells he had measured as undisturbed draw-wells, but did not state how he had ascertained that they were so. Although draw-wells were not worked so irregularly as those provided with pumps, yet, unless precautions were taken to ascertain that the wells had not been unduly drawn

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[1] RAINFALL.

Year.	Croydon.	The Denbies.	Excess at the Denbies.
	Inches.	Inches.	Per cent.
1871	24·54	33·35	36
1872	35·27	45·28	28
1873	25·71	31·01	21
Mean	28·51	36·55	28

upon before the observation, there was great liability to inaccuracy. The late Mr. Bland, of Hartlip, would not allow his well to be drawn upon, even for the slightest quantity, on the Sunday or Monday before an observation was made, so that it might be, as far as possible, free from any temporary disturbance. He fully agreed with Mr. Easton, that in districts where there was a probability of the fissures discharging towards the sea, the true plan was to run an adit or tunnel to intercept those watercourses. He was somewhat puzzled by the Author's "water contours." His own idea of a water contour was a line joining places at which the water stood at an equal altitude above Ordnance datum; but the Author stated that the accuracy of the line of Chalk Marl, and that of the Tertiary base, formed the governing elements of his water contours. If so, he did not know what water contours could be. If they depended upon geological formations, the application of the word "contour" was at any rate unfortunate. He liked the term "hydrogeology," but the science was not a new one. Mr. Clutterbuck had read a Paper before the Institution, in 1842, "Observations on the periodical drainage and replenishment of the subterraneous reservoir in the Chalk Basin of London."[1] The Author had given an immense number of observations of importance, in which if there had been any serious errors, they would no doubt have been pointed out. It would be a great improvement, however, if the wells were, by latitudes and longitudes, more clearly identified. Mr. Bland had given him some years ago a copy of his original memoranda, referred to by Mr. Clutterbuck, and which, at his request, he would hand in.[2] They were of great interest, and would be of still greater if the same district could be re-surveyed after the lapse of more than half a century. He had been much puzzled by the statement of Mr. Latham as to the temperatures in Godstone quarries. Possibly, however, he might not have thought of the influence of a current of air in those quarries upon a thermometer when taken out of the water. As long as the thermometer remained in the water it would show the temperature of the water, but as soon as it was taken out it became a wet-bulb thermometer, and would fall; and the more delicate the instrument the more liable it was to this error. It was just possible that in that way low temperatures had been obtained. With regard to Clark's process, he always considered water softened by that method to be insipid. Mr. Chadwick had stated that the conductors of the Geological Survey had not strictly confined themselves to superficial geology. Even if their instructions had been so to confine themselves, the officials of the department certainly had not done so. When some years ago he was making experiments upon a deep artesian boring in the north of London, a member of the Survey very soon visited him. He was getting up a memoir on the subterranean water in London, which he believed was the finest contribution to the subject that had ever been made. Very extensive inquiries, in fact a hydrogeological survey on a large scale, had been made with respect to the levels of the water in connection with the Kennet and Avon canal, which he should be happy to place at the disposal of any member of the Institution who wished to pursue the subject.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 155.

[2] *Vide* "The Philosophical Magazine and Annals of Philosophy," 1832 [new series], vol. xi., p. 88.

Mr. GROVER, referring to the statement by Mr. Evans, that the gradient of the water on the north side of London was 12 feet per mile, said he had been investigating the wells in the north of London, being engaged in sinking a deep well at Hampstead Hill, and had found that the fall was 16 feet per mile. He had mentioned that fact to Mr. Evans, who had said there was no doubt that the fall varied from 12 feet to 19 feet. All the wells from Hyde Park to the City were of the same type, and appeared to reach water within 30 or 40 feet of the same depth, and the water appeared to rise in them to an average level of about 50 feet below Ordnance datum. The Harrow well struck water at 186 feet below datum, and the water rose to a height of 101 feet above datum. At the Orphan Asylum, Haverstock Hill, there was another well, where the water was reached at 215 feet below Ordnance datum, and rose to 20 feet below datum, and this gave a gradient of 16 feet per mile. That was checked by the Lower Hampstead Heath well, sunk in 1833 for the New River Company, but which had since been stopped. He was now sinking near that point a well 540 feet deep, which he expected would have the same conditions. Carrying the line on, he found that it cut the datum almost exactly at Lower Hampstead Heath, and the report of the well there was, that the water did correspond to the Ordnance datum. He desired to draw attention to one point, because it was a question that he could not solve. Where did the water go? There was a gradient, and of course there must be a flow of some kind. If it flowed into the river, the water ought to rise in the wells to the surface of the river, as it did when a well was sunk near the sea-coast; but it did not rise to within 50 feet of Ordnance datum. Was it possible that the upper water which flowed down above Ordnance datum passed by some spring or other into the river, and had no connection with the water below, or was the London consumption of water wholly the cause of the 50-feet depression? He had sunk a well for the Bognor Waterworks, near the Sussex coast line, 330 feet deep. He had made a calculation before the works were started from the results obtained at Worthing, and assumed, if water was reached in the same bed of flints as at Worthing, it ought to be attained at a depth of 300 feet, and his contract was framed accordingly. At that depth, however, no water was found; but as soon as 30 feet more had been reached, the rods went down with a jump, showing that they had got into a fissure. The water then rose in the well to the level of the sea. Curiously enough, a well had been sunk at Chichester through the same strata without reaching sufficient chalk water. How was that to be explained? Just as in sinking a shaft to reach old workings in a coalpit, one might go through some of the unworked ground or pillars left by the men to keep the roof of the mine from falling in, so he thought it possible that the reason why the water was ever missed in chalk was, that the beds containing it had been in some places so compressed by the upheaval of the palæozoic rocks underneath, or the pressure of the Tertiaries above, that there ceased to be any space for the water to pass through, and the boring happened to hit one of these spots.

Mr. **Bramwell** said the Author had spoken of the futility of borings, and had given what he considered a reason for his view, which, however, was no reason at all. Abundant testimony had been offered by Mr. Homersham and Mr. Easton, and could be multiplied over and over again, of instances in which a large supply of water had been obtained by boring. On the other hand, near the seashore where underground rivers existed, running down towards the sea, a ready way of getting water was to make an adit parallel to the sea, so as to intercept the subterranean channels one after another. The final conclusion of the Author appeared to be that it would not do to depend upon any large supply of water from the Chalk; but he had wholly failed to prove this. Rain fell upon the Chalk, and the water had to be got rid of in one of three ways. Either it must go into the ground, or it must be evaporated, or it must form rivers. As to forming rivers, Mr. Homersham (who had paid much attention to the subject) many years ago adopted the most conclusive method of showing what the rivers in chalk countries were as compared with the rivers in other districts. On an

Ordnance map he selected a number of watersheds, say of 10 square miles above various bridges. He then sent to the districts, had drawings made of the bridges, and instituted inquiries. With catchment areas upon the Chalk equal to those upon other soils, it was found that while, in the case of the other soils, there would be a bridge with two or three large arches, and at times a considerable rise of water in the river, amounting even to heavy floods, in the chalk districts there would be found bridges single and small arched, and an almost invariable level of water. That being tested over and over again, it was a thoroughly practical proof, if any proof were needed more than observation in walking over the country, that the Chalk Formation did not produce large rivers, and therefore that the water did not run off the Chalk to the same extent as it ran off other soils. What then became of it? Unless there were great extra evaporation from the Chalk, the rainfall must sink into the Chalk; and if it got into the Chalk, it could not stop there for ever—it must overflow or in some other way escape, as indeed it did. In places it appeared as springs upon the surface; while in others it flowed by underground channels to the sea, and could be intercepted by boring or by driving tunnels. Although, as Mr. Longridge had stated, there seemed to be among the philosophers a great discord as to what could and what could not be done in the Chalk, the fact was, that while scientific men had been making the discord, engineers, like Mr. Easton and Mr. Homersham, had been quietly getting the water and supplying the populations. That was a sufficient answer. The thing was being done and was done, and it was no use under such circumstances to argue that such a supply was unattainable. With regard to the quantity, he quite agreed with the observations of Mr. Longridge, that the value of the percolation gauges to which he had referred was very doubtful. He supposed it was a fact that the evaporation all over the earth and sea was equal to the rainfall all over the earth and sea. If it were not so, the water would either be up in the sky, and stop there, or would remain below and the land would be deluged. Rainfall and evaporation must therefore be equal, taking it all round. But it was not equal upon the land. If it were there would be no rivers. Yet observations had been made with certain gauges which, if followed out to their legitimate conclusions, would show that there was on the land an amount of evaporation that would leave no water at all for the purposes of rivers. But even assuming that the suggested 6¼ inches of water were absorbed per annum, 1 square mile would give a quarter of a million gallons a day. It had been stated by Mr. Homersham, and had been published (paragraph 88, Metropolitan Water Supply Commission, 1869), that the area of the Chalk was 1,047 square miles above Kingston, and including the area below that spot, the Thames basin contained double that number of square miles. There was therefore an enormous area from which a supply could be obtained. He was very glad to hear Mr. Chadwick's retraction, although it was a late one, for it was a quarter of a century since he had expressed his opinion the other way, it was very gratifying to find him now coming forward and saying that he had been in the wrong, and that those who opposed him had been in the right. The use of Clark's process, except that lime-water was employed instead of milk of lime, had not altered from what it was twenty-five years ago. The only difference was that the process was now believed in, while then it was not. Mr. Wanklyn had stated as a reason why Clark's process was not applicable to the Kent water, that it was impossible to soften that water below 7°. That appeared to him, however, to be an inconclusive reason. If the original hardness was 24°, surely it was a great benefit to soften it down to 7°, which indicated by no means hard water, but water quite as soft as anybody would like for potable purposes. A hardness of 24° was a serious matter to deal with, especially in regard to washing; and when there was a process which would get rid of 17° out of 24°, it passed his comprehension why it should not be used simply because 4° more could not be got rid of and the water be brought down to 3°. The fact was no doubt this, that the Kent Company did not wish to be under the imputation of serving one customer with soft water and another with hard, and that therefore when they became possessed of the Plumstead waterworks, they gave up the softening as being a simpler mode of delivering a uniform quality than that of the only other mode open to them, viz., going to the expense of putting down plant adequate to soften their whole supply. As regarded the fitness of this water for softening, the Government now had that very water softened for them at Shooters Hill. It was clear, therefore, that there were some persons who believed that Clark's process was applicable to the Kent water. He might mention that quite recently an improvement had been made in the Clark process by Mr. J. H. Porter, an improvement which promised very well. It was now for the first time being put to work to soften the chalk water at Banstead Asylum to the extent of 60,000 gallons a day. The process dispensed entirely with the settling tanks formerly required. Instead of the lime-water and the hard water being run together into tanks, and allowed to settle for twelve or fourteen hours, the mixed water was passed through filters which entirely took out the precipitate. Each filter would deliver 1,800 gallons an hour for ten hours without appreciable diminution. The filtering medium was not the cloth alone, but the cloth plus the first deposit of chalk which took place. He was glad to find that the magistrates of Middlesex had determined to put the system into operation at the Banstead Lunatic Asylum; and he believed it would be found that Mr. Porter's system would be very useful for small consumers, although not perhaps for water companies, who would continue for their great consumption to use depositing tanks.

Mr. Lucas, in reply, said that his strictures upon borings were not general, but applied only to those which were misplaced. The limitations of the case were clearly defined in the Paper. He had met with a boring at Halsted, in Kent, on the chalk hills. Much as he deprecated borings in such positions, he equally censured shafts in artesian areas of overflow. The simple rule was: above the water-line, a shaft; below it, a bore—modified in every case according to local conditions. The theory of a bore-hole, as it appeared to him, was to liberate water; that of a shaft, to reach water. As Mr. Homersham and others appeared not to be very clear as to what Chalk Marl was, he had brought a specimen with him. Objection had been raised to his calling it a stiff clay; but if any gentleman would walk 36 miles along it in two days he would probably allow it a fair average amount of tenacity. The whole dispute with reference to the question of quantity seemed to resolve itself into a criticism as to the value of the two registers of absorption—Mr. Evans's and Mr. Greaves's. They were closely concurrent; taking the average of 6 inches, which they seemed to indicate as absorbed over the Chalk of the Thames basin, he did not see how more water could be got out of the Chalk than was recorded as passing into it. He had nowhere stated that the gradient at the minimum water-line was steeper than the gradient at the maximum, except in reference to a very short line at Epsom, as described in Appendix. As a general rule, the altitudes given in the tables would be found to be near the truth. In an original survey of this kind, the object was to bring a wide sweep of country well under the eye. He preferred employing his time in extending the area of observation, to accurately levelling the height of a few wells, which would be done for the whole country at some future time. Mr. Latham appeared to be puzzled by the movement and the variation in form of the water-line at different seasons. The first of these points had been treated by himself in "Horizontal Wells," 1874, in which he had demonstrated a series of waves flowing down the water-line, at observed intervals after the falls of rain to which they were due. The variation in form of the water-line had been expressed in the present Paper. The sanitary issues of the subject mentioned by Mr. Latham had first been pointed out by himself in an article on Wells, in the "Architect" of the 29th of July, 1876. He had purposely avoided the large question of temperatures, from a sense of its great importance; but since it had been dragged into the discussion, he would merely state that, at equal elevations above the sea, the water in the Chalk was much warmer than that in the Lower and Upper Greensands; and water rising in artesian districts from equal depths below sea-level, came up much warmer from the Chalk than from the Thanet Sand. He felt sure that the temperature of 47° Fahr. was never found in the Chalk Water System. The range in temperature on the hills was from 49° to 52°, and in the artesian districts from 52° to 55°·5 Fahr., at 214 feet below O.D. In the Lower Greensand hills it was from 47° to 49°·5. Upper Greensand wells in the Chalk area gave a temperature much below that of the surrounding chalk wells.

Hydrogeology, as a science, was admitted by all; but Mr. Symons had questioned the Author's claim to have raised the subject to that rank, in support of which he had reproduced a section published in the "Philosophical Magazine" of February 1832, by Mr. Bland. The section traversed a line of country about 18 miles in length, exhibiting three ranges of hills—the Chalk, the Lower Greensand, and the Lower Wealden Sands. The section treated these several water systems as if they were all one, the water-line being drawn through the barriers of the Chalk Marl, the Gault, and the Weald Clay, all of which had been omitted. Notwithstanding that forty-five years had elapsed since the publication of that section distinguished by such gross errors, not only had Mr. Symons reproduced it to-day, but other modern sections containing the same mistakes had been hung on the wall by Mr. Easton and Mr. Baldwin Latham. Mr. Easton had run a water-line through the barrier of the Chalk Marl to the Upper Greensand springs at Titsey. Mr. Latham had drawn a line through two barriers through which no flow of water could take place; the higher being the Chalk Marl, and the lower the Gault. Several gentlemen had alluded to the mass of contradictions and the great differences of opinion upon the most elementary points brought out by the discussion on the Paper. He heard in them the same old story of five-and-twenty years ago, that had run through every Blue Book published since. He contended, since the utmost that had been done with former observations was to reduce them to the sectional form, most of which, in the absence of complete evidence, were erroneous, the conditions of a science were not fulfilled, as laid down in the masterly definition of Froude, which being very much to the point he would cite. "What are the conditions of a science? and when may any subject be said to enter the scientific stage? When the facts of it begin to resolve themselves into groups; when phenomena are no longer isolated experiences, but appear in connection and order; when, after certain antecedents, certain consequences are uniformly seen to follow; when facts enough have been collected to furnish a basis for conjectural explanation, and when conjectures have so far ceased to be utterly vague, that it is possible in some degree to foresee the future by the help of them. Till a subject has advanced as far as this, to speak of a science of it is an abuse of language."

All these conditions were fulfilled in his maps and sections, and his was the first collection of a sufficient mass of evidence to render the construction of hydrogeological maps possible. The scientific existence of a subject of this kind must be held to date from the construction of the first map.

In answer to Mr. Chadwick, he did not call in question Sir Henry de la Beche's personal attainments. What he affirmed was that the scope of the survey founded by Sir Henry de la Beche was limited to the science of physical geology. As a matter of fact, he had served nine years on the staff of that Survey, and he was, therefore, in a position to state that the evidence of wells was only taken for the sake of the geological section they afford. While on the staff he had made an application to be allowed to carry on the present work, but the subject was repudiated by the Survey as not forming part of the work covered by their grant. He therefore undertook the present hydrogeological survey himself. As a pioneer, he had encountered the usual obstructions, but he had had his reward in the fact that the first results of his labours had been read and patiently listened to by The Institution of Civil Engineers.

Mr. DUGALD CAMPBELL remarked, through the Secretary, that he had in the course of a long experience analysed water derived from nearly every source of supply throughout the kingdom, and particularly water from wells sunk in chalk not covered with clay, and likewise from wells sunk in chalk covered with clay. His views coincided with those of Mr. Homersham as to the quality of the water derived from these two sources being different. For the sake of comparison, he submitted a table of the results of the analyses of water from these two sources of supply. Great care had been taken to shut out from the wells all surface water, and indeed all other water than what they derived from the strata into which they had been sunk.

TABLE of ANALYSES in GRAINS per GALLON.

Substances found in the Waters.	Waters from Wells in Chalk not covered with Clay.			Waters from Wells in Chalk covered with Clay.		
	Caterham Water Supply.	Chiltern Hills Water Supply.	Canterbury Water Supply.	Trafalgar Square, Orange Street Well.	Combe and Delafield's Well, Long Acre.	De Keyser's Well, Victoria Embankment.
Carbonate of soda	..	..	..	10·58	11·60	14·67
Sulphate of soda	1·10	2·00	..	21·34	24·25	15·90
Chloride of sodium	1·55	1·17	3·00	19·04	12·70	13·18
Chloride of potassium	1·96	1·20	0·45	1·05	a trace	2·51
Carbonate of lime	13·00	12·96	15·96	2·74	6·18	1·15
Sulphate of lime	1·21	a trace	0·08	..	..	1·60
Nitrate of lime	..	a trace	2·06	..	..	0·07
Magnesia (probably as silicate)	0·46	0·37	0·29	..	..	..
Carbonate of magnesia	..	..	..	2·07	1·08	2·16
Silica	1·04	1·44	0·96	0·40	0·44	0·88
Oxide of iron	0·80	0·30	0·16	..	..	0·04
Phosphates of iron and lime	..	..	..	0·97	0·43	a trace
Volatilised matter	0·80	0·72	0·96	0·66	0·12	0·16
Total	21·92	20·16	23·92	58·85	56·80	52·32

This proved that the water obtained from wells in chalk not covered with clay, which had percolated through chalk, in so doing took up and held in solution a considerable amount of chalk (carbonate of lime), whilst the water where there was an overlying bed of clay held in solution comparatively little chalk, but contained large quantities of soda-salts, as carbonate, sulphate, and chloride of sodium, or common salt. Where this water came from, or whence the salts of soda were derived, had been a puzzle to chemists who had attempted to investigate the source of supply of this water. For several years before 1857 he had been engaged in making analyses of water from the deep wells under London with this object, and in that year he read a paper before the Chemical Society,[1] in which he had been obliged to confess his inability to give a satisfactory explanation. During that investigation he observed that the chalk under London, as Mr. Homersham had remarked, was much harder than chalk not overlaid with clay, that it did not absorb water to any extent, and that under similar circumstances it was usually incapable of allowing water to percolate through it like other chalk, and was repeatedly intersected with thin veins of gypsum in small hard crystals, which assisted in preventing the percolation of water.

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[1] *Vide* "The Quarterly Journal of the Chemical Society of London," vol. ix., p. 21; "On the Source of the Water of the Deep Wells in the Chalk under London."

One of the most marked differences between these waters was seen when the lime process of the late Dr. Clark was applied to them. Where the Chalk was overlaid with clay little or no change took place, but when it was applied to the water that had percolated through chalk alone, it improved it materially by removing nearly all the chalk in solution, leaving the water very soft and pure.

Sir Walter Farquhar furnished, through the Secretary, the particulars of the well at Polesden Park, Leatherhead, ascertained on the 14th of December, 1876. Total depth, 507 feet; from the lowest stage of pumps to the bottom of the well, 207 feet; from the bottom of the stage to the water, 45 feet. Water, 162 feet deep and rising fast. Temperature of the water, 56°, taken by a man holding a thermometer in the water while sitting in a rope sling.

Mr. Rogers Field remarked, through the Secretary, that although several instances had been cited during the discussion to show the inaccuracy of the Author's statement as to hydrogeology being a new science not four years old, one of the most striking instances of all had not been alluded to, viz., the hydrological map of the Department of the Seine, by M. Delesse, Ingénieur des Mines. This map was published in 1862, by order of Baron Haussmann, and was a perfect example of what a hydrogeological survey ought to be. It was drawn to a scale of $\frac{1}{25000}$ (about 2½ inches to 1 mile). It showed the levels of the ground by black figures and black contours, the levels of the surface water by blue figures, and the levels of the underground water by contours and figures of various colours, according to the geological strata in which these waters were held. There were also geological references and geological sections, with the levels of the underground water marked on them, besides levels of wells (artesian as well as ordinary), and numerous other details.

Although the Paper was valuable as containing a large collection of measurements of wells and other data bearing on the question of the water in the Chalk, he felt bound to point out that many of the conclusions arrived at were very misleading. He would take one or two instances. It was stated that the amount of absorption of rain necessary to maintain the water at its minimum level was half that which was necessary to maintain the water at its average level. The reasoning by which the Author arrived at this conclusion was by no means clearly expressed, but he believed that the following was a fair statement of it:—

(1.) At Chilgrove on one occasion (in the year 1853), when the water was 1 foot below its mean height, it rose 58 feet in ninety-two days, and then began to fall again. (Table 5.)

(2.) The calculated absorption of rain in these ninety-two days was 2·97 inches, or at the rate of ·03228 inch per diem.

(3.) This rate of absorption, if continued, would maintain the water at the maximum height to which it rose at the end of the ninety-two days.

(4.) Hence the amount of absorption necessary to maintain the water-level at 56 feet above its mean height was ·03228 × 365, or 11·78 inches per annum.

(5.) But the absorption necessary to maintain the water at its mean height was 6·58 inches.

(6.) Hence by proportional differences the absorption necessary to maintain the water at its minimum height (or 36 feet below its mean height) was 3·29 inches.

(7.) Half of 6·58 inches was 3·29 inches, and therefore the degree of absorption necessary to maintain the water at its minimum level was half that necessary to maintain it at its average level.

Now almost every step of the above reasoning had been based on erroneous or doubtful assumptions. In step (1) it was assumed that the rise of 58 feet took place in ninety-two days, whereas the detailed tables No. 3 showed that it actually took place between the 31st of August and the 31st of October, or in sixty-one days instead of ninety-two days. In step (2) it was assumed that the calculated absorption during ninety-two days was the supply which caused the rise of 58 feet. This was, at any rate, doubtful. In step (3) it was assumed that the mean daily absorption during the time the water rose to a given height was the supply necessary to maintain the water at that height. No explanation was given of this assumption, and it was not borne out by the data in the Paper. It was evident that the amount of supply necessary to maintain the water-level at any height must increase regularly with the height, but a reference to Table 5 would show that the mean daily absorption during the rise of the water to different heights did not so increase, and consequently differed from the supply. Step (4) depended on steps (2) and (3), and was, therefore, doubtful. In step (6) it was assumed that equal increments of supply gave an equal rate of rise, whether the water was high or low. This assumption the Author himself stated farther on to be inaccurate, and he gave a table showing its inaccuracy, which, however, was itself misleading. In step (7) it was assumed that the results of a single year and in one locality could be safely applied to deduce general conclusions.

To take another instance of a questionable conclusion, the absorption necessary to maintain the water-level at its maximum height was stated in the Paper to be 16·21 inches annually. This was also calculated by a very similar method to that by which the absorption necessary to maintain the water-level at its minimum height was calculated, and therefore, as explained above, was unreliable.

Again, it was stated that the same amount of rain absorbed produced a greater amount of rise when the water-line was high than when it was low, and a table was given in the text which apparently proved this. But an examination of the details in Table 5 would show that this table was only compiled from four out of the seven instances in the detailed table, and if they had all been included the results would have been so irregular as to have precluded the deduction of any rule. In fact the deductions and conclusions in the Paper must be received with the greatest possible caution.[1]

Mr. GREAVES observed, through the Secretary, that he agreed with the Author in his opinion as to the moderate amount of water in the Chalk. It was useless to propound that there was no water in the Chalk, or that a vast store of water existed, from which millions of gallons might be drawn. Many wells and bores had been failures, though the facts they certified were more instructive than those that had been successful. The failures were not so well reported as the successful ones, and were often not reported at all. The results of the Author's inquiry belonged rather to the petty well-borer and well-sinker's art than to the subject of water in large quantities. An equally exact and circumstantial statement of the draught of all the steam-worked pump wells, though their number might not exceed fifty, would afford knowledge of a much more valuable nature. The largeness of the supply of water obtained from some sources in the Chalk had established a belief in the existence of crevices, and it was these crevices about which knowledge was most wanted. That they existed in places, that they were not universal, and were in some parts absent, was a conclusion to which most people had come. Borings through the Chalk were not uncommon; a supply from below the Chalk was a matter of familiar expectation with many, and ever since the issue of Professor Prestwich's work on the water-bearing strata of the country around London had been looked upon as an operation almost to be relied on if funds for the work were forthcoming. The late Mr. Morris was of opinion that the district occupied by the Kent Waterworks had many crevices, and that if a well sunk after the best prospects and judgment failed to prick a source, still that a source could at no great distance be reached by lateral heading. It was at least so found in the Kent district, where on one occasion the miners had to beat a hasty retreat, leaving all their tools behind them in one of the wells there sunk, and from which a heading of some length had been extended. A few years since the argument in favour of water in the Chalk seemed to be that large volumes existed generally throughout the formation; that water in bulk was stored thus, having sunk down many years ago. But his conclusions were that water from these sources was probably due to the rain of the previous winter, or wet winter at most.

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[1] Mr. Field seems to think the Author has an exaggerated opinion of the results of the method of analysis given in Table 5. The Author upholds the method, but admits that the results are necessarily approximate only, as they rest wholly upon the imperfect registers therein collected. The Author has now seen the excellent map by M. Delesse, alluded to by Mr. Field as having, to their credit, been published by the French Government.—J. L.

In a well sunk many years ago by the New River Company in Hampstead Road, the gushes of water compelled movable shields to be slung to enable the men to put down pumps.

In another well sunk by the late Mr. William Mylne at Amwell Hill, the first planned set of pumps were considered insufficient in dimensions for the water that was obtained; but in enlarging the well only for the reception of a pair of larger pumps, a far more copious spring was cut, which until that moment had been inclosed by a wall of chalk of trifling thickness.

In the well at Haverstock Hill no water was found, though the depth exceeded 1,200 feet, and water was absolutely sent down the well to keep the cutting tools of the jumper-head cool, and to render easier the withdrawal of the material by the shell.

In the springs at Grays the proximity to the Thames was suspicious. The water accumulated rapidly in the open working of a chalk-pit, and was not sought by means of wells or boring; but there were obvious crevices which were a source of trouble in the Lower Chalk workings, until by concentrating the pumping, the water over a small area had been exhausted, and then the spout of water was walled up in its own crevice. So the workings proceeded until another crevice was cut and plugged. These crevices had been described by the late Mr. Meeson as frequently full of a semi-liquid chalk, which was washed out by the force of water, thus greatly enlarging the crevices. This source of water supply was good up to certain limits, but those limits could only be ascertained by practice. Other borings might strike the same crevice, and no rights were secure beyond territorial possession. He had in 1863 sunk a well in the Chalk, of large dimensions, at the instigation of a director of the East London Water Company. The well was 80 feet deep from the surface, and terminated in a boring of about 300 feet, but the result was a failure, as the flow of water was not ½ inch deep over the edge of a 12-inch pipe when cut off 2 feet above the floor of the well. The Chalk, in fact, proved to be what well-sinkers term bull-headed; it was uniform, solid, and close, without flints or crevices. He agreed with the remark that solid chalk was impervious to water; but he thought the power of capillary attraction had been overrated. The Chalk, to commence with, was partially saturated, and he believed there was a limit of depth where, according to the season, capillarity and gravitation balanced one another. Indeed, if capillarity were so active a force as had been represented, it might be called into operation to raise water to levels to which it is now lifted by mechanical means. He believed that in the district under discussion, viewing the turf over the chalk soil as a maximum evaporator, the average percolation would be barely 5 inches, with a variation from year to year from a maximum of 8 inches to a minimum of 1 inch. It would be interesting to connect the crevices from which the water was obtained with the district where it was collected by percolation. He thought he had some evidence of this kind in the patriarchal well of the New River Company, known as the Chadwell spring, of which old Bunaby said, nearly one hundred and fifty years ago:—

> "Fontes lentem dantes sonum
> Quæ ditarunt Middletonum."

Now this spring had been known to yield 500 cubic feet of water per minute. Where could such a copious flow originate? There was a district generally considered to lie outside the river Lee watershed, and to belong to the river Colne, where in ordinary seasons no permanent outfall or river connection appeared, but in extremely wet seasons a bourne connected the district with the Colne. The area of this basin was 26 or 27 square miles; its focus was about 10 miles from the Chadwell spring; and he considered that a crevice from one basin to the other was all that was necessary to account for this copious discharge of water.

The Rev. D. S. Halkett stated, through the Author, that springs of water had never been known to break out near Orestan Farm; but that a remarkable bourne had once appeared at the north-west corner of Little Bookham churchyard, and that in a field in Effingham parish, close to the boundary of Little Bookham parish, a spring sometimes broke out in a bed of gravel.

The Earl of Lovelace observed, through the Secretary, that he had long instinctively felt that the Chalk Formation could not be relied upon for a great and permanent yield of water. There were several instances within a few miles of East Horsley, in which great expense had been incurred in sinking wells and afterwards in pumping by steam, and where, after all, the owners had been obliged to resort to tanks and reservoirs in order to obtain an adequate supply. He had in East Horsley and in the adjoining parish of Effingham constructed tanks in brick and cement for the various homesteads and cottages belonging to him, probably not less than fifty; and although expensive in the first instance, the result had been satisfactory and the yield of water generally adequate. When this system was adopted it was of course desirable that the buildings should be designed and the roofs covered in such a way as to favour the rapid delivery into the tanks of all the water that fell on their surface. The summits of the chalk hills in the neighbourhood were in places largely capped with clay. This soil was not very good for tillage, and the want of water rendered it unsuitable for the pasturage of any stock but sheep. It might possibly be planted with advantage, and the result by increasing the rainfall would help to remedy the deficiency in the subterranean stores of the Chalk. He could not but feel that this deficiency would be seriously felt in the course of even this generation.

Mr. Morris explained, through the Secretary, in reply to Mr. Grant's question, that when the Kent Waterworks Company took possession of the works of the Plumstead, Woolwich and Charlton Consumers' Pure Water Company, Limited, which had been wound up in the Court of Bankruptcy, his father, the late Mr. W. R. Morris, M. Inst. C.E., found the apparatus put up by Mr. Homersham for mixing the cream of lime with the water out of order, owing to the pipes connected with it being choked by the too rapid deposition of the carbonate of lime, and the operation of softening carried out in a very rough manner. The experiment at Plumstead had not been altogether so successful as to induce his father to recommend the company to incur any further expenditure in the matter, and the softening process was abandoned. Mr. Homersham's arrangements for softening the water at the Herbert Hospital by means of lime-water, instead of cream of lime as at Plumstead, were complete and successful, but somewhat costly, and it appeared to him questionable whether the cost of softening the water would not exceed the alleged saving to be effected by its use for domestic purposes; it was now generally admitted that waters of moderate hardness were not injurious to health, and the fact should not be lost sight of that rain-water was always available for washing, and was largely used for that purpose.

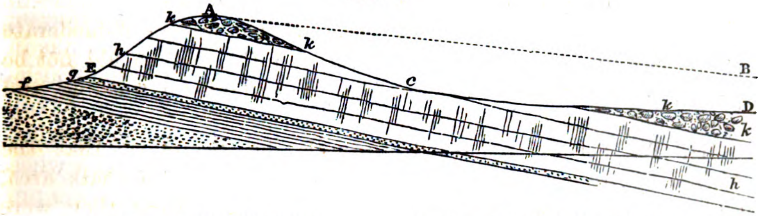
Mr. W. TOPLEY remarked, through the Secretary, that the Author had referred to the intermittent springs of the chalk area, which were generally known as 'bournes'; in Kent they were often called 'nailbournes'; in Sussex, 'levants'; in Dorset and Hants, 'winterbournes'; in Yorkshire, 'gypsies.' These curious springs deserved more attention than had hitherto been paid to them.

They broke out suddenly, and only after unusually wet seasons. They did not follow the heavy rainfall immediately, but only after an interval of a few months, in fact after the rain had had time to percolate downwards and to raise the water-level. They generally appeared in the upper part of the valleys, and ran down a valley-bed which was previously dry. Various explanations had been offered of this. In most cases the following simple reason seemed sufficient, which had been hinted at by the Author (Fig. 2):—

The dip of the beds of chalk underlying the valley was generally steeper than the slope of the valley-bed; so that in ascending the valley the lower beds of chalk were successively passed over, until the steeper rise of the valley-head was reached near the escarpment, when the slope of the ground became greater than the dip of the beds. It was at or near the point where this change took place that the bournes generally broke out; they broke out near the point at which the lowest beds were exposed. Rain-water accumulating in the Chalk rose chiefly and most rapidly along the lines of bedding. Where the lowest beds were exposed, there the spring first appeared. The breaking of the bourne was often foretold by a rapid rising of water in the wells lower down the valley, but the bourne generally flowed down the valley before the water in these wells actually rose to the surface.[1] Sometimes, indeed, the true water-level of the wells did not rise to the surface. In this case, as the Author had pointed out, the bourne disappeared beneath the surface, unless prevented from doing so by a clayey covering of the valley-bottom.

The great majority of bournes might be explained in this way; but probably in some cases this explanation might be insufficient, and Professor Prestwich's siphon theory would be required.[2]

FIG. 2.



k = Upper Chalk (with flints).
g = Upper Greensand.
AE = Chalk Escarpment.
AcD = Slope of Valley-bottom.
AB = Slope of Plateau.

h = Lower Chalk (without flints).
f = Gault.

c = Outburst of Bourne.

In Dorsetshire there was a belief that the winterbournes only broke with a gale from the south-west. For this, as for all such popular beliefs, there was probably some small foundation in fact. It was likely that, when the Chalk was charged with water up to the "breaking point," a sudden fall of the barometer, such as almost invariably accompanies south-westerly gales, might suffice to determine the exact period of the outburst. It would be interesting to know whether this belief was held in other districts, and what foundation there might be for it.

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[1] The foregoing explanation and illustrative example have been given by Mr. Topley in the Memoirs of the Geological Survey, vol. iv., p. 392, 1872. (" The Geology of the London Basin.")

[2] *Vide* "The Water-bearing Strata of the Country around London," p. 73.

PUBLIC STANDARDS OF LENGTH.

Sir G. B. AIRY, Chairman of the Commission of Standards, stated that several years ago the Commission reported to Her Majesty's Government the desirableness of establishing, in secure and accessible places, public standards of length; and from time to time examination was made of stations which seemed to be suitable for their location. One difficulty after another presented itself, till at length Mr. Wilfrid Airy, M. Inst. C.E., suggested a locality in Trafalgar Square, on the north side of the fountains, and ranging close under the retaining wall of the Square. The place was inspected by members of the Standard Commission and by the Warden of Standards, and was fully approved. Due application having been made to the Commissioners of Her Majesty's Works (in whose district the place is situate), and to the Board of Trade (by whose authority the funds for expenses connected with standards are provided), the necessary permission and powers were obtained, and the actual execution of the work was intrusted to Mr. W. Airy. The metallic part was constructed by Mr. James Simms, of the firm of Troughton and Simms. The exactitude of the measures was verified, after the severest examination and comparison with the fundamental legal standards, by Mr. Henry W. Chisholm, Warden of Standards, and Mr. H. J. Chaney, of the Standards Office.

The lengths laid down are: a line of 100 feet, divided into parts of 10 feet each, with smaller subdivisions at one end; and a line of 66 feet or a chain, divided into parts of 10 links each, with smaller subdivisions at one end. There is the strongest reason to believe that each of these entire lengths is correct within $\frac{1}{100}$ inch, and that the errors of the subdivisions are proportionally small.

There is also a tablet containing standards of the yard measure and subordinate parts.

Finally, by Order of the Queen in Council, the standards of 100 feet and 66 feet are declared to be Legal Standards; and reference to them in any case of disputed length is accordingly valid.

It is hoped that the construction of these standards will be acceptable to the Institution of Civil Engineers, whose works depend so much on the accuracy of very long measures, to which these standards are specially applicable.

December 5, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The following Candidates were balloted for and duly elected:—William Carson, Thomas Rhodes Firth, Hubert Garbett, William Inglis, James Kitson, Jun., John Napier, William Milnor Roberts, Robert Robinson, and Frederick Thomas Granville Walton, as Members; William Ashdown, Thomas Bevington, Arthur Frederick Borradaile, Henry Taylor Bovey, M.A., Stud. Inst. C.E., Lieut. Charles Frederic Call, R.E., Samuel Cooke, M.A., John Corbett, M.P., David Cowan, Griffith Nathaniel Cox, Stud. Inst. C.E., Robert Davidson, Basil Pym Ellis, Lieut. Christopher Sullivan Feltrim Fagan, R.M.L.I., Maurice Frederick FitzGerald, Stud. Inst. C.E., William Henry Gibbs, James George Henry Glass, Theodore Graham Gribble, John Hayes, William Southwood Hedgman, Thomas Hewson, John Albert Reinhold Hildebrandt, Washington Hume, James Charles Inglis, Stud. Inst. C.E., John William James, Owen Jones, Stud. Inst. C.E., William Gibbs Kerle, Llewellyn Lloyd, Henry Eugene MacMahon, Stud. Inst. C.E., William Frederick Mayes, Nicolas Outine, Charles Preller Sheibner, Ph.D., Frederick Slade, Charles Henry Sparkes, Thomas Lanfear Tanner, Walter Thomas, Stud. Inst. C.E., Thomas Debell Welsh, John Hamilton Wicksteed, Stud. Inst. C.E., and George Nicholas Yourdi, as Associates.

It was announced that the Council, acting under the provisions of Sect. iii., Cl. 7, of the Bye-Laws, had transferred Frederick Morris Avern, Peter John Bruff, John George Gamble, M.A., Robert Trefusis Mallet, William Matthews, and Robert Hunter Rhind from the class of Associates to that of Members.

Also that, under the provisions of Sect. iv. of the Bye-Laws, the following Candidates, having been duly recommended, had been admitted as Students of the Institution:—Robert Anderson, William Robert Bagley, Edgar Frank Barry, Edward Herbert Blackburn, George Rudolph Bodmer, Palmer Augustus Bourke, B.E., T.C.D., Ralph Henry Browne, Charles Ernest Bruges, John Adye Buchan, Charles Edward Carden, Jesse Fairfield

Carpenter, William Richard Hopkins Chipperfield, George James Clarke, Charles Hamlet Cooper, Robert Goodacre Cope, William Henry Robinson Crabtree, William Santo Crimp, Joseph Cox Dear, Herbert William Edlin, William Henry Fisher, Henry Walter Ford, Singleton Goodwin, Henry Haywood Jones, William Barrow Kendall, Henry Ashworth Lucas, Allan Arthur Grenville Malet, Henry Capner Marks, Leonard Swaine Mortlock Marsh, Horace Richard Marwood, George Barker Mercer, William Burton Saville Mills, Hugh Hamlyn O'Connell, Christopher William Page, Charles Berkeley Penlington, Edgar Philip Rathbone, Alfred Richard Sennett, John Augustus Thompson, Gerard Philip Torrens, John Clough Vaudrey, Otto Weiss, Edward Wilson, and Richard John Woods, B.E., T.C.D.

The discussion upon the Paper No. 1,461, "The Chalk Water System," by Mr. Joseph Lucas, occupied the whole evening.

December 12, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The discussion upon the Paper No. 1,461, "The Chalk Water System," by Mr. Joseph Lucas, occupied the whole evening.

ANNUAL GENERAL MEETING.

December 19, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The list of members nominated as suitable to fill the several offices in the Council was read.

Messrs. C. E. Hollingsworth, W. Matthews, R. C. May, T. M. Smith, F. Stevenson, J. Thomson, and A. Williams were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Ballot having been declared open, the Annual Report of the Council, on the Proceedings of the Institution during the past year, was read. (*Vide* page 173.)

Resolved,—That the Report of the Council be received and approved, that it be referred to the Council to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner; the title of the separated Members of the Associate Class being reserved for future decision.

Resolved,—That the thanks of the Institution are due, and are presented to, Messrs. Charles Frewer and William Henry Barry, for the comprehensive statement of Receipts and Payments they have prepared; and that Messrs. William Henry Barry and R. Price Williams be requested to act as Auditors for the ensuing year.

Mr. Frewer returned thanks.

The Telford and Watt Medals, the Telford and Manby Premiums, the Miller Scholarship, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 196 and 197.)

Resolved,—That the thanks of the Institution are justly due, and are presented, to the Vice-Presidents and other members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Bateman, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Stephenson, President, for his persevering endeavours in the interests of the Institution, for his unremitting attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Stephenson, President, returned thanks.

Resolved,—That the best thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their zealous and valuable services on behalf of the Institution and of the profession.

Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected:—

President.

GEORGE ROBERT STEPHENSON.

Vice-Presidents.

James Abernethy.
Sir W. G. Armstrong, C.B., F.R.S.
William Henry Barlow, F.R.S.
John Frederic Bateman, F.R.S.

Other Members of Council.

Members.

Sir Joseph Wm. Bazalgette, C.B.
Isaac Lowthian Bell, M.P., F.R.S.
George Berkley.
Fred. Jos. Bramwell, F.R.S.
George Barclay Bruce.
James Brunlees.
Sir John Coode.
Harrison Hayter.
William Pole, F.R.S.
Charles William Siemens, F.R.S.
Sir Jos. Whitworth, Bart., F.R.S.
Edward Woods.

Associates.

Col. G. C. Collyer, R.E.
Henry Oakley.
Col. J. T. Smith, R.E., F.R.S.

Resolved,—That the thanks of the Meeting be given to Messrs. Hollingsworth, Matthews, May, Smith, Stevenson, Thomson, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

[Annual Report.

ANNUAL REPORT.

SESSION 1876-77.

ONE of the duties devolving upon the Council is to "draw up a yearly Report on the state of the Institution." That obligation the Council elected in December last now proceed to fulfil. They approach this task with the belief that the time and attention bestowed upon the affairs of the Society have in every way been productive of advantage to the Corporation, as well as of benefit to its individual members.

THE CONSTITUTION OF THE SOCIETY,

which was alluded to in the two previous reports, has again received careful consideration. According to the present classification, no distinct provision is made for the large number of Engineers who are past the age when they can remain Students, but have not yet occupied such positions, nor been so employed, as to render them eligible for Members. Hitherto it has been the practice to recommend such candidates for election as Associates; hence it has come to pass that this class comprises more than two-thirds of the whole body—an undesirable result, and one that was certainly not contemplated when the original Regulations were framed, for in those Regulations Associates were described to be persons "who are not Engineers by profession." The Council advise that in future the definition of Associate should be so restricted, and that the class should no longer include persons practising the profession, as defined in the Charter.

The omission referred to is proposed to be supplied by the creation of a new class. The selection of a suitable title for this has been a matter of great difficulty. For weighty reasons, it has been deemed desirable to preserve the title of Member and that of Associate, to indicate respectively the classes previously so designated. Some expression had therefore to be found which would fairly and properly represent the position of the new class.

With this end several suggestions were made and fully discussed, and, simple as it may appear, there were objections to almost every title brought forward. As the result of long and anxious deliberation, the Council recommend the term "Associate-Member," as being open to the least objection.

Adhering as closely as possible to the wording of the present Bye-Laws as to Members, the Rule for the proposed class might be:—

> ASSOCIATE-MEMBERS.—Every Candidate for admission into the Class of Associate-Members, or for transfer into that Class, shall come within the following conditions—
>
> He shall be more than twenty-five years of age; shall (either by pupilage with a Civil Engineer or otherwise) have acquired the requisite knowledge for following, and shall be actually engaged in some of the branches defined by the Charter as constituting, the profession of a Civil Engineer.

The altered Rule as to Associates, being, in truth, a return to the original Regulations already noticed, setting forth the first intention of the composition of this class, would read thus:—

> ASSOCIATES shall be persons of more than twenty-five years of age, who are not Civil Engineers by profession, but whose pursuits are allied to engineering, or who otherwise, by their connection with Science or the Arts, are qualified to concur with Civil Engineers in the advancement of professional knowledge.

It is suggested that the Associate-Members, although not enjoying in every respect the same privileges as Members, should, in common with them, have the right to make, alter, and establish Bye-Laws at Special General Meetings. As regards the Contributions to the Funds, if the rates for Members and Associates are to remain unaltered, then an Associate-Member might well be called upon to pay a mean between the subscriptions of those two classes, in which case the Rule would stand thus:—

> Each resident Associate-Member shall pay three and a half guineas, and each non-resident Associate-Member three guineas per annum.

The Council think that, as an addendum to Rules which have been found to work well for nearly sixty years, the proposals submitted for approval are worthy of the most favourable consideration. If these proposals receive the sanction of this meeting, then it will devolve upon the new Council to revise the Rules in accordance with the spirit of these instructions, and to call a Special General Meeting of Members only, for the purpose of their enactment.

Elections into the Corporation.

The continuous accessions to the roll of the Institution bear witness to the fact, that it has fairly made good its claim to be considered as the official representative and guardian of the profession. During the past session no less than 221 candidates, recruited from every branch of engineering, and in themselves a greater number than composed the entire corporation forty years ago, were elected. Of these, 34 were received directly as Members, while 187 were made Associates.[1]

With respect to the preponderance of Associates, it may be remarked that a large number of candidates for election into the Institution are young men, whose practice and experience do not

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[1] The tabular statement for the years 1874–75 and 1875–76, of the transfers, elections, deceases, resignations, and erasures of the members of all classes belonging to the Institution, that is, exclusive of the Students, is as follows:—

Year.	Honorary Members.	Members.	Associates.	
1874–75.				
Transferred to Members . .	..	..	17	
Elections	3	33	176	212 – 57 = 155
Deaths	4	15	22	57
Resignations	..	2	6	
Erased from Register . . .	..	1	7	
Members of all Classes on the Books, 30th November, 1875	14	823	1,447	2,284
1875–76.				
Transferred to Members . .	..	..	20	
Elections	..	34	187	221 – 45 = 176
Deaths	..	13	22	45
Resignations	..	..	5	
Erased from Register . . .	..	..	5	
Members of all Classes on the Books, 30th November, 1876	14	864	1,582	2,460

as a rule allow of their being at once admitted as Members. Some years must therefore elapse before they can arrive at the necessary qualification of "at least five years' responsible professional charge of adequately important engineering works," or of a considerable degree of eminence in the profession, and thus become eligible to be transferred by the Council to the Member class, as 20 Associates were in the past session. Taking the number of Members as unity, the relative proportion of Associates at intervals of five years, commencing November 1856, has been 1·54, 1·46, 1·42, 1·44, and 1·83. There has been no change among the Honorary Members, the number remaining at 14, as at the same date last year. The net effective additions of Members and of Associates have been 41 and 137 respectively, together 178, bringing up the number of members of all classes on the books (exclusive of the Students) to 2,460 on the 30th of November last, or an increase at the rate of nearly 8 per cent. in the year. Eleven years ago this gross total was 1,203, and in December 1862 it was exactly 1,000.

The following deaths were announced during the past year; the bracketed figures after some of the names referring to the volumes of "Proceedings" in which memoirs have already been printed:—

MEMBERS: Charles Frederick Beyer (*post*), James Fairrie Blair, Crawford James Campbell (xlv., 241), Richard Smith Clayton (*post*), Arthur John Dodson (xlv., 243), Frederick East (xliii., 299), William Galwey, James May (xlv., 244), Robert Milligan (*post*), Robert Napier (xlv., 246), Joseph Philip Ronayne, *M.P.* (xlvi., 274), Edward Baliol Scott (xlv., 276), and James Stirling (xliv., 221).

ASSOCIATES: Henry Anderson, Robert Aytoun (*post*), William Barber (*post*), Benjamin Burleigh (*post*), William James Cadett, Seymour Clarke (xliv., 225), Charles Berwick Curtis, James Dredge, William Oliver Gooding (xlv., 251), *Sir* William Jackson, *Bart.* (xlv., 252), Evan Leigh (xliv., 229), *Lt.-Col.* Clement John Mead (*post*), William Chadwell Mylne (xliv., 231), Francis Napier (xliv., 232), Elihu Henry Oliver (xlv., 256), George Pothecary (xlv., 257), James Robertson (xliv., 234), Richard Stephen Roper (xlv., 259), Peter Soames (xlv., 260), George Thompson (xlv., 261), Peter Thomson (xliv., 235), and John Hooper Wait (xlv., 262).

Among the Members who had passed away were two eminent engineers, Mr. Robert Napier and Mr. Beyer, who, by dint of their own great qualities, raised themselves from the humble sphere wherein they were born to the foremost rank in the profession; while the ingenuity and perseverance of a third, Mr. Stirling, in respect of the hot-air engine, cannot be passed unnoticed. The deceased Associates numbered at least one name rendered historic in the annals of engineering, as well as two worthy representatives of the class of great contractors, to whom engineers owe so much for co-operation afforded in realising their ideas.

Five Associates, viz., James Broadbridge, Frederick George Finch, Jeremiah Jowett, Charles Mumford, and *Captain* Robert Francis Taylor, have withdrawn from the Institution.

Admission of Students.

The above enumeration is exclusive of the Students, who are admitted by the Council. Into this class 119 candidates were received during the past session; on the other hand, 32 were elected Associates, and the names of 25 were, from various causes, removed from the list, leaving a net increase of 62. From the date of the establishment of this class in 1867 to the close of last session, or in a period of nine years, 696 candidates have been admitted; of that number 384 were on the books on the 30th of November last, while of the remainder 158 had been elected Associates, and 154 had ceased to be attached to the Institution. Each successive year shows a larger number of candidates for election into the Corporation from the Student class, and the time seems steadily approaching when it will be the principal source from which the bulk of the new members will be derived.

Contributions to the Funds.

No change has been made in the scale of Subscriptions of the several classes of members since the 26th of December, 1837, when Residents were defined to mean those living within ten miles of the General Post Office, and Non-residents, those beyond such limits; and this rule has been acted upon ever since. All the circumstances have in the interval been so materially altered, that it is open for serious consideration, whether the scale should not now be revised, and whether the time has not also arrived when the area for "Residents" should include the whole of the United Kingdom.

The numbers of Residents and Non-Residents in the various classes, with the amounts of Annual Subscriptions actually received last year from each class, are as follow:—

Class.	Residents.	Non-Residents.	Totals.	Subscriptions. £. s. d.
Members . . .	330	534	864	2,620 5 6
Associates . . .	644	940	1,584	4,295 11 0
Honorary Members	7	7	14	0 0 0
Students . . .	176	209	385	696 3 0
Totals . . .	1,157	1,690	2,847	7,611 19 6

Life Compositions in lieu of Annual Subscriptions have been paid by 85 Members and by 56 Associates.

The arrears of Subscriptions remaining overdue on the 30th of November last were from—

	£.	s.	d.
Members	133	17	6
Associates	178	10	0
Students	28	17	6
	341	5	0[1]

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[1] This amount has since been reduced to £278 15*s*. 6*d*..—Sec. Inst. C E.—*Dec.* 19, 1876.

THE SESSION AND MEETINGS.

There were twenty-six Ordinary Meetings during the past session, when nineteen Papers were read and discussed. The average attendance at these meetings was 226—or more than 5 per cent. in excess of the average number of the last ten years. The character of the Original Communications and of the remarks to which they gave rise may be gathered from the printed records in the four volumes of "Minutes of Proceedings" issued to the members at intervals throughout the year. Nine other Papers were selected for publication in the second section of the "Proceedings." To the Authors of fifteen out of these twenty-eight Essays—chosen from a much larger number submitted to the Institution—Premiums have been awarded as follows:—Telford Medals and Premiums to Walter Raleigh Browne, *M.A.*, William Cawthorne Unwin, *B.Sc.*, and Gilbert Richard Redgrave; Watt Medals and Telford Premiums to William Shelford[1] and Gabriel

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[1] Has previously received a Telford Medal.

James Morrison; Telford Premiums to Charles Bontemps, Richard Spelman Culley, John George Gamble, *M.A.*, Wilfrid Airy, *B.A.*, Sidengham Duer, *B.Sc.*, George James Symons, Charles Greaves, William Sugg, and James Nelson Shoolbred, *B.A.*; while the Manby Premium has been bestowed on David Alan Stevenson, *B.Sc.* Of these fifteen recipients six are Members and six Associates of the Institution, while the remaining three do not belong to the Society, and one of this number is a foreigner. These facts are mentioned, because it is sometimes erroneously supposed that strangers cannot directly present Memoirs to the Society, and are not eligible to receive the Premiums the Council have at their disposal.

The "Minutes of Proceedings" may be considered as affording a complete index of the progress of engineering in this country and in the Colonies since the date of their first publication in 1837. At the date mentioned the exact sciences were seldom invoked in designing works, so as to insure the greatest economy both of labour and of material. The earlier volumes are chiefly confined to detailed and faithful records of the construction of works, useful in that they show the average practice of the period. Railway construction was then being commenced; the locomotive engine was in its infancy; and the proper value of iron for bridges and other large structures was only beginning to be understood. Now, to maintain his relative position in the world, the Civil Engineer must possess an intimate knowledge of the fundamental principles of the physical sciences by which to govern his practice. The recent volumes of the "Proceedings" show that great progress has been made in this direction.

The "Abstracts of Papers in Foreign Transactions and Periodicals," forming the third section of the "Proceedings," continued to engage the attention of the Council, who have received abundant proofs that their labours in this direction are appreciated in many quarters. Important works, described in the journals of kindred institutions abroad, have always had a prominent place; and although the progress of engineering on the Continent has been, to a great extent, arrested by the general stagnation, the technical journals contained ample materials from which useful information has been obtained. At the same time, the Abstracts have included, not only studies of a purely scientific and theoretical nature, but memoirs and results of costly and laborious experiments, the details of which it would be impossible to obtain in any other English publication. There has thus been collected a vast number of facts which, though isolated, are frequently of great importance; and the requests, from various quarters, for further particulars give satisfactory evidence of their being perused with interest. Occasionally the Authors are at the pains to furnish the Institution with Abstracts prepared in part by themselves; and they have sometimes communicated additional and newer information. The number of Abstracts printed in the volumes relating to the last Session has been 220, occupying about 440 pages, or an average of exactly 2 pages each.

It has not yet been found possible, as promised last year, to complete a catalogue of the articles on engineering subjects that have appeared in the most important periodicals, principally because the preliminary work of classification is not so easy as was anticipated; but the plan has not been abandoned, and will, it is hoped, be shortly brought to maturity.

In addition to the Ordinary Meetings there were fifteen Supplemental Meetings for the reading and discussion of Papers by Students. Of the Papers submitted, one on the "History and Theoretical Laws of Centrifugal Pumps," by the *Hon.* Richard Clere Parsons, *B.A.*, has been awarded a Miller Scholarship of £40 per annum, tenable for three years. Of the remainder, eight were considered deserving of Miller Prizes, adjudged to Arthur Ernest Baldwin, George Barclay Bruce, Jun., Richard John Gifford Read, Joseph John Tylor, Joseph Tysoe, William James Chalk, Arthur Spence Moss, and Arthur Cameron Hurtzig. The average attendance at these meetings was 19 in place of 24 in the previous session. A total of 78 Students took part in these proceedings, of whom 63 resided within 20 miles of the Institution. One Student attended every meeting, while 33 were present on one occasion only.

With regard to the prizes offered under the will of the late Mr. Joseph Miller, it should be generally known that, according to the terms of the bequest, these can only be given to Students of the Institution.

Through the courtesy of several gentlemen, the Students have had opportunities of seeing manufacturing operations of an engineering character—a privilege that may be further developed with great advantage.

The Council have recently had under consideration a memorial from the Students, in which they have been asked to print and circulate a selection of the Papers submitted by the Students. This request has been favourably entertained, and it has been determined to print, in the second section of the "Proceedings," any Papers by Students containing original information of importance sufficient to warrant their appearing in the publications of the Institution.

THE PROPERTY OF THE INSTITUTION.

On the credit side of the statement of receipts and expenditure, it will be noticed that the total nominal value of the funds has now reached £36,816 4*s.* 9*d.* Of this amount the sum of £14,322 3*s.* 1*d.* represents the various funds held under trust, and the balance, £22,494 1*s.* 8*d.*, is the absolute property of the Institution. Adding the cash balance £326 11*s.* 7*d.*, the total becomes £37,142 16*s.* 4*d.*, at the end of the financial year, as compared with £35,297 15*s.* 8*d.* at the date of the previous Report. The various securities have been inspected by the Auditors, and show that the sum of £12,366 4*s.* 9*d.* is placed in Government stocks yielding 3 per cent., and the remainder, £24,450, stands in nearly equal proportions in guaranteed stocks of eight of the principal railway companies, yielding a fraction over 4 per cent.

To the foregoing statement of the property of the Institution it may be added that during the present year a sum of £1,704 12*s.* 6*d.*, including £35 17*s.* 2*d.* owing from 1875, has been invested on capital account. This has purchased £118 Manchester, Sheffield and Lincolnshire Railway 4½ per Cent. Debenture Stock, and £1,500 Great Western Railway 4 per Cent. Debenture Stock. But inasmuch as the Life Compositions, and Admission and Building Fund Fees of new members amounted to £1,877 8*s.*, there remains a balance of £208 12*s.* 2*d.* due from income, which will have to be added to the sum to be invested in 1877. The items mentioned in the last Report as due to the Telford and the Miller Funds, respectively £24 5*s.* 6*d.* and £118 19*s.* 3*d.*, have been repaid, these amounts having purchased £25 11*s.* 6*d.* and £125 11*s.* 1*d.* Three per Cent. Consols. The total of the investments of the year has therefore been £1,847 7*s.* 3*d.* as against £2,307 9*s.* 4*d.* in 1875.

Analysing still further the financial transactions of the year, it will be found that the income proper was £8,468 19*s.* 3*d.*, while the Trust Funds produced £459 19*s.* 3*d.*, and the Life Compositions, Admission and Building Fund Fees together £1,877 8*s.*, as previously stated. The two first-named sums are in excess of the same items last year by £415 10*s.* 4*d.* and £3 13*s.* 3*d.*; whereas the amount received on account of capital is £236 15*s.* 6*d.* less, owing mainly to the smaller number of life compositions. During the same time the general expenditure amounted to £4,833 9*s.* 6*d.*

(after giving credit for donations of £39 7*s.* to the Library Fund) the outlay on account of trusts was £313 7*s.* 8*d.*, and the disbursements for "Minutes of Proceedings" (after deducting the contributions to the Publication Fund and the money received for sale of Transactions) was £3,730 15*s.* 11*d.* To these have to be added, in order to effect a balance, the sum of £1,847 17*s.* 3*d.*, invested on account of capital and of unexpended Trust Fund dividends, and an excess in the cash balance, as compared with last year, of £80 16*s.* 2*d.*

These results are not, however, so favourable as they appear, the Institution being indebted to the printer and to the engraver for the last two volumes of "Proceedings"; as also to the Telford Fund, £20 9*s.* 6*d.*, the Miller Fund, £109 9*s.* 1*d.*, the Howard Fund, £65 9*s.* 8*d.* (four years' dividends), and to capital £208 12*s.* 8*d.*

So far only the money property has been referred to. The other effects include the lease of the premises in the occupation of the Institution, held for a term of ninety-nine years, at a net rental of £658 7*s.* per annum, of which eight and a half years have expired, with the option of purchase, for a net sum of £16,766 13*s.* 4*d.*, up to Midsummer 1878. Also the stock in hand of the forty-six volumes of the "Minutes of Proceedings," numbering together about 7,000 volumes, and the pamphlet editions of many articles reprinted from the "Proceedings."

But above all stands the Library—unrivalled and unique of its kind—the result not of recent labours alone, but also of the liberality of many early donors. Three years ago the library contained 10,443 volumes; now it consists of 13,431 volumes, an increase of very nearly 3,000 in the interval, being at the rate of 1,000 volumes annually. In the past year the collection has been carefully examined, the title of every book in the catalogue has been revised, and the subject entries for all works, exclusive of the tracts, have been completed. The missing parts of imperfect sets of serial publications have in many cases been obtained, and care is taken to keep all periodicals up to date. The binding account has been heavy, and must continue to be so, compared with previous years, owing to the large increase in the number of English and foreign transactions, proceedings, tracts, &c. The foreign journals alone exceed 100. Many catalogues of books for sale are searched, and any work that seems appropriate or likely to be useful to the members is secured. Several old and rare books have in this way been obtained.

Nor must the collection of portraits of Past-Presidents and other eminent Engineers be forgotten, to which there has lately been added a portrait of Joseph Miller, by *Sir* William Boxall, *R.A.* It will be remembered that Mr. Miller was a liberal benefactor to the funds, having bequeathed a sum of £3,000 "for providing premiums or prizes for the Students of the Institution," as well as a further sum of £2,000 for the general use of the Society.

The Books, Original Drawings, Portraits and Furniture are insured for £10,000.

MEETINGS OF OTHER SOCIETIES.

Acting under Sect. xiii., Cl. 2, of the Bye-Laws, which gives them the power to grant the use of the rooms for any purpose connected with the objects of the Institution, the Council have this year had the gratification to extend these facilities to the Institution of Mechanical Engineers, the North of England Institute of Mining and Mechanical Engineers, the Meteorological Society, the Society of Telegraph Engineers, the Iron and Steel Institute, the Association of Municipal and Sanitary Engineers, &c.

And here it seems to be the proper place to record the friendly offers received from the American Society of Civil Engineers and the Franklin Institute, to place their rooms, library, and services at the disposal of any one belonging to the Institution who might this year visit the United States, either in connection with the Philadelphia Exhibition or otherwise. Those members who availed themselves of the facilities so hospitably provided, speak in high terms of the cordiality of their reception, and the Council feel assured that the members at this General Meeting will indorse the action already taken, in tendering hearty thanks to the Societies named.

THE HONORARY SECRETARY.

In the last Annual Report attention was directed to the fact, that the Institution, and the profession at large, had enjoyed for nearly twenty years the important and entirely gratuitous services of the Honorary Secretary, Mr. Manby. In commenting upon this section of the Report Mr. Harrison, the then President, observed that the Council had determined to ask the Members and Associates to join them in recognising the value of these services in a substantial manner.

The Council have now much pleasure in stating that from the sources indicated there has been received a sum of £4,213 9*s*. 1*d*., increased by bank interest during the period of collection to £4,231 3*s*. 9*d*. Out of this the amount paid for postage was

£24 5*s.* 8*d.*, for a silver salver, engraved with the names of the subscribers, £115, and the balance, £4,091 18*s.* 1*d.*, formed the purse handed to Mr. Manby. Appended to this Report will be found a copy of the letter of presentation from the President, with the names of the contributors, and Mr. Manby's reply.

CONCLUSION.

From this Report it may be gathered that the past year has been one of continued progress and prosperity. In the somewhat depressed state of every branch of commerce, and of nearly every profession, it is no small criterion of popular confidence that the number of new members of all grades was greater than in any former year, that the average attendance at the meetings exceeded that of the last ten years, and that the interest taken in the Papers read and in the subsequent discussions has been fully maintained. The relations of the Institution with the members of the profession in the Colonies and abroad have been strengthened; and kindred societies in foreign countries have hailed the liberal spirit with which their contributions to engineering science and experience have been acknowledged in the "Minutes of Proceedings."

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

			Dr.	£.	s.	d.	£.	s.	d.
			To Balance in the hands of the Treasurer				250	13	6
			— Subscriptions and Fees:—						
			Arrears	148	11	6			
			Current	7,415	2	0			
			Advance	48	6	0			
			Life Compositions	105	0	0			
			Admission Fees	686	14	0			
							8,403	13	6
			— Building Fund				1,085	14	0
			— Publication Fund				181	6	0
			— Library Fund				39	7	0
			— Publications:—Sale of Transactions				143	13	5
			— Miscellaneous Receipts				2	18	0
			— Deposit Interest				15	17	9
			— Dividends: 1 year on						
£.	s.	d.							
			Telford Fund.						
2,839	10	10	Three per Cent. Consols	84	6	0			
2,586	0	11	Three per Cent. Reduced	76	15	5			
2,377	10	5	Three per Cent. Consols (Unexpended Dividends)	70	11	8			
841	12	9	Three per Cent. Reduced (Ditto, ditto)	24	19	8			
							256	12	9
			Manby Donation.						
200	0	0	Great Eastern Railway Co., Norfolk, Five per Cent. Preference Stock	..			9	18	2
			Miller Fund.						
2,000	0	0	Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	79	5	0			
1,100	0	0	Great Eastern Ditto	43	11	9			
582	18	6	Three per Cent. Consols (Unexpended Dividends)	17	6	1			
1,242	15	2	Three per Cent. Reduced (Ditto, ditto)	36	17	11			
							177	0	9
			Howard Bequest.						
551	14	6	New Three per Cents	..			16	7	7
			Institution Investments.						
3,650	0	0	Great Eastern Railway Four per Cent. Debenture Stock	144	12	10			
3,000	0	0	London and North Western Ditto	118	17	6			
1,500	0	0	London, Brighton, and South Coast Ditto	59	8	9			
3,000	0	0	North Eastern Ditto	118	17	6			
3,000	0	0	Great Northern Ditto	118	17	6			
£28,472	3	1	Carried forward	£560	14	1	£10,583	2	5

from the 1st DEC., 1875, *to the* 30th NOV., 1876.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street, for Rent, &c.:—						
Repairs	247	9	2			
Rent	652	12	11			
Rates and Taxes	56	13	3			
Insurance	30	6	6			
Furniture	21	4	6			
Oil Painting	46	16	6			
				1,055	2	10
— Salaries				1,700	0	0
— Clerks, Messengers, and Housekeeper				689	3	0
— Donation to late Housekeeper				30	0	0
— Postage and Parcels:—						
Postage	119	5	0			
Parcels	3	17	8			
				123	2	8
— Stationery, Engraving, Printing Cards, Circulars, &c.				261	15	10
— Light, Fuel, &c.:—						
Coal and coke	35	12	6			
Candles	0	5	5			
Oil	0	6	8			
Gas	53	5	0			
				89	9	7
— Tea and Coffee				37	18	3
— Library:—						
Books	257	17	5			
Periodicals	56	12	6			
Binding	290	14	4			
				605	4	3
— Publication, "Minutes of Proceedings"				4,055	15	4
— Telford Premiums				236	3	3
— Watt Medals				2	7	6
— Manby Premium				9	12	9
— Miller Prizes				67	11	8
— Diplomas				33	1	6
— Manuscripts, Original Papers, and Drawings				2	13	10
— Annual Dinner (Official Invitations, &c.)				100	17	5
— Winding and Repairing Clocks				1	12	0
— Incidental Expenses:—						
Christmas Gifts	1	16	6			
Assistance at Ordinary Meetings	11	4	6			
Ditto at Students' Meetings	5	12	6			
Beating Carpets and Sweeping Chimneys	2	11	0			
Household Utensils, Repairs, and Expenses	101	17	4			
				123	1	10
Carried forward				£9,224	13	6

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.

£.	s.	d.		£.	s.	d.	£.	s.	d.
28,472	3	1	Brought forward . .	560	14	1	10,583	2	5
			To Dividends—*cont.*						
			Institution Investments: cont.						
1,000	0	0	Lancashire and Yorkshire Railway, Four per Cent. Debenture Stock	39	12	6			
1,500	0	0	Great Western Ditto—New Investment	0	0	0			
1,500	0	0	London, Brighton, and South Coast Ditto, Four and a Half per Cent. Ditto . .	66	17	5			
2,882	0	0	Manchester and Sheffield Ditto	128	9	6			
118	0	0	Ditto—New Investment (6 months)	2	12	6			
1,344	1	8	New Three per Cents . . .	39	18	0			
							838	4	0
£36,816	4	9	Total nominal or par value of Funds.				£11,421	6	5
			To Benevolent Fund Petty Disbursements, 1875.				11	4	8
							£11,432	11	1

from the 1st DEC., 1875, *to the* 30th NOV., 1876.

PAYMENTS—*cont.*

Cr.							£.	*s.*	*d.*
Brought forward							9,224	13	6
By Legal Expenses							16	5	0
— Surcharge on Subscriptions paid in 1874–5 refunded							1	1	0
							9,241	19	6
— Benevolent Fund Petty Disbursements, 1876							16	2	9
— Telford Fund.—Balance of Income not yet expended in Annual Premiums, invested in £25 11*s.* 6*d.*, Three per Cent. Reduced				24	5	6			
— Miller Fund.—Ditto, £125 11*s.* 1*d.*, ditto				118	19	3			
— Institution Investments:—									
£118, Manchester, Sheffield, and Lincolnshire Railway Four and a Half Per Cent. Debenture Stock	134	16	6						
£1,500 Great Western Four per Cent. ditto	1,569	16	0						
				1,704	12	6			
							1,847	17	3
— Balance Nov. 30, 1876, viz.:—									
Cash in the hands of the Treasurer				317	9	7			
" " Secretary:—									
Petty Cash	3	5	0						
Abstractors	5	17	0						
				9	2	0			
							326	11	7
							£11,432	11	1

Examined and found correct.

(Signed) CHARLES FREWER } *Auditors.*
W. H. BARRY }
JAMES FORREST, *Secretary.*

December 15*th*, 1876.

[Appendix to Annual Report.

APPENDIX TO ANNUAL REPORT.

THE MANBY FUND.

Letter of Presentation from the President of The Institution of Civil Engineers to CHARLES MANBY, F.R.S., M. Inst. C.E., Honorary Secretary.

THE INSTITUTION OF CIVIL ENGINEERS.
Established 1818.—*Incorporated by Royal Charter* 1828.
25 GREAT GEORGE STREET,
WESTMINSTER, S.W.
8th November, 1876.

DEAR MANBY,

The Council and a great number of members of The Institution of Civil Engineers, highly appreciating the value of the honorary services which you have, for upwards of Twenty Years, rendered to that Society and to the Engineering profession, depute me to ask your acceptance of a Purse of £4,088 15*s.* 1*d.*, and of a Piece of Plate inscribed with the names of the Contributors.

This gift is not intended in any way as a measure of your services, but is offered to you in remembrance of them, and you are requested to receive it as the friendly recognition of your unceasing efforts to maintain the high position of the Institution, and of your constant readiness at all times to assist its individual members.

With best wishes, I remain, dear Manby,
Yours faithfully,
GEORGE ROBERT STEPHENSON,
President.

Reply from CHARLES MANBY, F.R.S., M. Inst. C.E., to the President of The Institution of Civil Engineers.

24 GREAT GEORGE STREET,
WESTMINSTER,
9th November, 1876.

MY DEAR MR. PRESIDENT,

I am honoured by the expression, through you, of the kindly views entertained by the members of the Institution of the value of the services which I have endeavoured to render, as their Honorary Secretary, and I beg you to convey to them my best thanks, not only for the substance of the Testimonial, but more especially for the feeling by which it has been prompted, and the generous expression of their appreciation of my endeavours to be useful to the Institution collectively, and to the members individually. It has been my pride to see the reputation and the position of the Institution increased and assured, and more especially to find that its younger members emulated the conduct and bearing of the Founders and their successors, by whom it is only just to say that the Profession has been brought to its present eminence.

It has been a source of regret to me that increase of years and failing health have, for some time past, prevented my regular attendance at the Council table and at the meetings, but I knew that allowance would be made for me, and that my absence was not of importance so long as the Institution had the efficient services of my successor—the present Secretary.

I cannot attempt, Sir, adequately to express all that I feel towards yourself, the Past-Presidents, and the Members of Council, for their consideration of me at all times, and I can only say that the few remaining years of a somewhat long career will be willingly devoted to the interests of the Institution, as were those of a period when energy and decision were required to establish that which had been so wisely and beneficently devised by the Founders of our Society.

Pardon, Mr. President, my having so inadequately expressed what I feel, and be pleased to say to my good friends that I thank them from the bottom of my heart.

Believe me,
My dear Mr. President,
Yours very faithfully,
CHARLES MANBY.

George Robert Stephenson, Esq., M. Inst. C.E.,
President, &c.

The Silver Salver bears the following inscription, surrounded by the names of the Subscribers:—

Presented
TO
CHARLES MANBY, F.R.S., M. Inst. C.E., &c., &c.,
With a Purse,
In friendly remembrance of many years' valuable services as Secretary and Honorary Secretary of The Institution of Civil Engineers,
1876.

List of Subscribers.

Members.

Abernethy, J.
Adams, W.
Addison, J.
Airy, W.
Aitken, R.
Allport, H. A.
Amos, C. E.
Armstrong, Sir W. G., C.B.
Ashwell, J.
Atkinson, W.
Austin, C. E.
Ayris, J.
Baker, W.
Baldry, J. D.
Ballard, S.
Barlow, W. H.
Barns, J. W.
Barrington, W.
Barry, J. W.
Bassett, A.
Bateman, J. F.
Bayley, K.
Bayly, G. H.
Bazalgette, Sir J. W., C.B.
Beazeley, A.
Bell, C. N.
Bell, I. Lowthian, M.P.
Bell, William.
Benedict, E.
Berkley, G.
Bewick, T. J.
Bidder, G. P.
Blair, J. F.
Blandy, A. F.
Bower, Jno.
Boyle, R. V., C.S.I.
Bramwell, F. J.
Brereton, R. M.

Brereton, R. P.
Brind, A. W.
Broadrick, G.
Brown, T. F.
Bruce, G. B.
Brunlees, J.
Buddicom, W. B.
Bush, G.
Butler, J. O.
Byrne, H.

Carey, J. J.
Carter, W. B.
Cay, W. D.
Charlton, F.
Christy, F. C.
Clark, W.
Clegram, W. B.
Clerke, W. J. B.
Colthurst, J.
Coode, Sir J.
Cooper, E.
Crampton, T. R.
Cross-Buchanan, W.
Crouch, W.

Daglish, R.
Deacon, G. F.
Dempsey, W.
Douglass, J. N.
Douglass, W.
Drory, G. W.
Du Port, W. J.

Eachus, G. E.
Ellacott, J.
Elliot, Sir Geo., Bart., M.P.
Elliott, J.
Elsdon, W.
England, J.
Evans, F. J.

Fenwick, T.
Fernie, J.
Field, J.
FitzGibbon, A. C.
Forrest, R. E.
Forster, G. B.
Fowler, A. M.
Fowler, J.
Fox, C. D. & F.
Froude, W.
Fuller, G. L.

Gallott, J. L.
Giles, F.
Giles, G.
Gill, H.
Gooch, T. L.
Graham, J.
Graham, R. W.
Grant, J.
Greaves, C.
Greck, P.
Gregory, C. H, C.M.G.

Handcock, R.
Hanna, F. B.
Harris, E.
Harrison, A. R. C.
Harrison, J. T.
Harrison, Joseph.
Harrison, T. E.
Hartley, Sir C. A.
Hawkshaw, Sir J.
Hawkshaw, J. C.
Hawksley, C.
Hawksley, T.
Hayter, H.
Haywood, W.
Head, Jer.
Hederstedt, H. B.
Hellyer, G. W. M.
Hemans, G. W.
Hensman, H.
Hick, J., M.P.
Hickson, R. R. P.
Higginson, H. P.
Higinbotham, T.
Hill, G. H.
Hodgson, R.
Holt, A.
Hood, R. J.
Hooper, H.
Huntington, J. B.
Huxham, H.
Hyde, M.

James, J. W.
Jeffrey, R.
Johnson, Robert.
Johnson, S. W.
Jones, H. E.
Jones, Hodgson.
Jones, R.

Keeling, G. W.
Kennedy, J. P.
Kingsbury, W. J.
Kirby, F. H.
Kitson, J.
Knowles, J.

La Touche, H. C. D.
Lee-Smith, H.
Leslie, F.
Leslie, J.
Lewis, W. B.
Lindley, W.
Linn, A. G.
Lovell, T.
Lunn, R.
Lynde, J. G.
Lyster, G. F.

M'Clean, F.
McConnochie, J. A.
McDonnell, A.
Mair, J. G.
Marmont, J.
May, R. C.
Messent, P. J.
Miers, F. C.
Miller, J.
Mitchell, J.
Morton, R.
Mosse, J. R.
Muir, J.

Neate, C.

Oldham, J.

Paskin, J. A.
Paynter, L. W.
Penn, J.
Phillipps, W. F. M.
Phillips, D.
Phipps, G. H.
Pole, W.
Pollard, W. B., Jun.
Powell, W.
Price, W. H.
Prince, H.
Proctor-Sims, R.

Purdon, W.
Purser, E.

Quick, J. & Son.

Radford, W.
Ramsden, Sir J.
Ravenhill, J. R.
Rawlinson, R., C.B.
Rayne, M.
Redman, J. B.
Reid, G. L.
Rennie, G. B.
Richardson, J.
Ridings, H. S.
Robertson, H., M.P.
Robins, C.
Robinson, S.
Robinson, W. R.
Ross, O. C. D.
Rymer-Jones, T. M.

Saunders, A.
Scott, M.
Scott, W. H.
Scott, W. B.
Shand, J.
Sharp, J. F.
Sheilds, F. W.
Sibley, G.
Siemens, C. W.
Simpson, A. T.
Simpson, J.
Slaughter, E.
Smith, J. C.
Smith, J. T.
Smyth, W. S.
Sopwith, T., Sen.
Spice, R. P.
Stephenson, G. R. (*President*).
Stevenson, D.
Stileman, F. C.
Swettenham, W. N.

Taylor, J. (1846).
Taylor, J. (1848).
Taylor, J. (1862).
Teasdel, W.
Thomas, E.
Thorold, W.
Till, W. S.
Tucker, J. S.
Turnbull, G.

Upward, A.
Ure, J. F.

Vignoles, Hutton.

Wake, H. H.
Waring, H. R.
Waring, T.
Watson, R.
White, R.
Whitworth, Sir J., Bart.
Williams, A.
Williams, R. Price.
Wilson, E.
Winder, T. R.
Winter, T. B.
Wood, H.
Woodhouse, J. T.
Woods, E.

Yockney, S. H.
Young, E. W.

Associates.

Adams, W.
Adams, W. A.
Addy, J.
Aird, John, Jun.
Albrecht, C. J.
Allport, J. J.
Andrews, T.
Anstey, H.
Ashbury, T.
Ashton, T.
Ashworth, J.

Baker, W. L.
Balfour, D.
Ballard, R.
Barber, W.
Barr, J.
Barron, F. C.
Barry, W. H.
Bates, E.
Bayliss, J.
Bayliss, S.
Bazalgette, E.
Berrey, T. H. G.
Bessemer, H.
Biddell, G. A.
Bidder, G. P. Jun., Q.C.
Bigg-Wither, T. P.
Bird, J. B.
Blakesley, T. H.
Bohn, G.
Bonnin, W. W.
Borrer, W.
Boulton, S. B.
Bourne, J.
Braham, C. B.
Brassey, T., M.P.
Brown, J. (1866).
Browning, A. G.
Budd, G. O.
Burder, W. C.
Burgess, J.
Burleigh, B.

Cammell, C.
Campbell, W. D.
Chance, J. T.
Clark, J.
Clark, O. D.
Clark, Colonel Sir A., K.C.M.G., C.B., R.E.
Clutton, J.
Clutton, R. G.
Cock, W. H.
Coke, R. G.
Colyer, F.
Conyers, W.
Corry, E.
Cowan, C.
Crawford, R.
Croll, A. A.
Crosland, W. M.
Croucher, J. S.
Crowe, W. M.
Cursetjee, A.
Cuthell, A.

Daniel, C. E.
Davies, E. G.
Delano, W. H.
Denham, Rear-Adml. Sir H. M.

Donaldson, W.
Drake-Brockman, W.
Duckham, F. E.

Eastman, T.
Elliot, W.
Ellis, T. C.
Elwes, R. G.
Evans, Adml. George.
Evill, W.

Faber, Capt. C. W.
Faber, W. C.
Falshaw, Sir Jas., Bart.
Farmer, J. S.
Favell, T. M.
Faviell, W. F.
Ferrières, The Baron de.
Fletcher, L. E.
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Frewer, C.

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Harrison, H.
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Johnson, J. H.
Johnson, J. Thewlis.
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Michele, V. D. de.
Miers, J. W.
Miller, Lieut. J. F. J.
Miller, T.
Mitchell, F. D.
Moore, W. W.
Morris, W. (1872).
Mort, F. H.

Mumford, C.
Murzban, M. C.

Nelson, T. B.
Newbigging, T.
Newton, J.

Oakley, H.
O'Connell, Col. P. P. L., R.E.
Ogilvie, A.
Oldham, R. A.

Palmer, G.
Parry, A. W.
Patterson, M.
Paxman, J. N.
Pease, J. W., M.P.
Peggs, J. W.
Penn, J., Jun.
Penny, A.
Peto, Sir S. M., Bart.
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Pitt, R.
Pooley, H.
Prebble, C. T.
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Thomas, J. L.
Thomson, J. (1859).
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PREMIUMS AWARDED.

SESSION 1875–76.

THE COUNCIL of The Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, to Walter Raleigh Browne, Assoc. Inst. C.E., for his Paper on "The Construction of Railway Wagons, with special reference to Economy in Dead Weight."
2. A Telford Medal, and a Telford Premium, to William Cawthorne Unwin, B.Sc., Assoc. Inst. C.E., for his "Investigation of the Motion of Light Carriers in Pneumatic Tubes, when the Air is in continuous or permanent Motion."
3. A Telford Medal, and a Telford Premium, to Gilbert Richard Redgrave, Assoc. Inst. C.E., for his Paper on "Sewage Interception Systems, or Dry-Sewage Processes."
4. A Watt Medal, and a Telford Premium, to William Shelford,[1] M. Inst. C.E., for his Paper on "The Treatment of Sewage by Precipitation."
5. A Watt Medal, and a Telford Premium, to Gabriel James Morrison, M. Inst. C.E., for his Paper on "The Ventilation and Working of Railway Tunnels."
6. A Telford Premium to Charles Bontemps, for his Paper on "Experiments on the Movement of Air in Pneumatic Tubes."
7. A Telford Premium to Richard Spelman Culley, M. Inst. C.E., and Robert Sabine, Assoc. Inst. C.E., for their Paper on "The Pneumatic Transmission of Telegrams."
8. A Telford Premium to John George Gamble, B.A., Assoc. Inst. C.E., for his Paper on "The Brighton Intercepting and Outfall Sewers."
9. A Telford Premium to Wilfrid Airy, B.A., M. Inst. C.E., for his Paper "On the Probable Errors of Levelling, with Rules for the Treatment of Accumulated Errors."
10. A Telford Premium to Sidengham Duer, B.Sc., Assoc. Inst. C.E., for his Paper on "The Hydraulic Canal Lift at Anderton, on the River Weaver."

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[1] Has previously received a Telford Medal.

11. A Telford Premium to George James Symons, Secretary to the Meteorological Society, for his Paper "On the Floods in England and Wales during 1875, and on Water Economy."
12. A Telford Premium to Charles Greaves, M. Inst. C.E., for his Paper "On Evaporation and on Percolation."
13. A Telford Premium to William Sugg, Assoc. Inst. C.E., for his Paper "On Estimating the Illuminating Power of Coal Gas."
14. A Telford Premium to James Nelson Shoolbred, B.A., M. Inst. C.E., for his Paper "On the Changes in the Tidal Portion of the River Mersey, and in its Estuary."
15. The Manby Premium to David Alan Stevenson, B.Sc., for his Paper on "The Dhu Heartach Lighthouse."

The Council have likewise awarded the following Prizes to Students of the Institution:—

1. The Miller Scholarship to the Hon. Richard Clere Parsons, B.A., Stud. Inst. C.E., for his Paper on "The History and Theoretical Laws of Centrifugal Pumps as supported by Experiment, and their Application to their Design."
2. A Miller Prize to Arthur Ernest Baldwin, Stud. Inst. C.E., for his Paper "On Tunnelling in the London Clay."
3. A Miller Prize to George Barclay Bruce, Jun., Stud. Inst. C.E., for his Paper on "The Rio Tinto Mines Tunnel."
4. A Miller Prize to Richard John Gifford Read, Stud. Inst. C.E., for his Paper "On Metallic Veins, and on Works in connection with Tin Mining, and on the Dressing of Tin Ores."
5. A Miller Prize to Joseph John Tylor, Stud. Inst. C.E., for his Paper on "The Sinking of a Coal Pit in the Rhondda Valley, with particulars of the means employed and of the cost of the work."
6. A Miller Prize to Joseph Tysoe, Stud. Inst. C.E., for his "Description of a Grain Warehouse and Malting, and of the Apparatus used for removing and distributing the Grain."
7. A Miller Prize to William James Chalk, Stud. Inst. C.E., for his Paper "On some Methods of Screwing Piles, adopted in the Construction of the Withernsea Pier."
8. A Miller Prize to Arthur Spence Moss, Stud. Inst. C.E., for his Paper on "Underpinning, with recent Examples."
9. A Miller Prize to Arthur Cameron Hurtzig, Stud. Inst. C.E., for his Paper on "Concrete in Marine Works."

SUBJECTS FOR PAPERS.

SESSION 1876–77.

THE COUNCIL of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will be prepared to award Premiums, arising out of special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) now produces nearly £260 annually.

2. The MANBY DONATION, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings," of the value of £10 a year.

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) now realises about £170 per annum. Out of this Fund the Council have determined to establish a series of Scholarships,—to be called "The Miller Scholarships of The Institution of Civil Engineers,"—for Papers from Students, and to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to rather more than £16. It is proposed to award this prize every five years, commencing in 1877.

The Council will not, in any case, make an award unless a communication of adequate merit is received; but, on the other hand, more than one Premium will be given, if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made between essays received from a Member, an Associate, or a Student of the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

List.

1. The Triangulation Survey, and Mapping of Countries and Districts, including the Astronomical Observations required for latitude and longitude, the measurement of bases, the description of the different instruments and methods employed, the reduction of the observations, and degree of accuracy of the results.
2. The Levelling of Countries, either by Spirit-levelling, vertical angles, barometers, or the boiling-point of water; with a description of the instruments employed, the reduction of observations, and degree of accuracy of the results.
3. The existing Standards of Mechanical Power in different Countries.
4. The Varieties of Clay, and their respective values and treatment, for brick-making, for puddle, and for the construction of Embankments, whether for railway purposes, reservoirs, or dock walls.
5. The nature of Slips in Rocks and Earths of different kinds, and the Conditions that induce treacherous ground in Railway-cuttings, tunnels, and the sides of valleys near reservoir banks.
6. The Application of Steam Machinery for Excavating, and the Cost as compared with Hand Labour.
7. The Process of Forging by Steam Hammers and other Percussive Machinery, and by the Hydraulic Press.
8. The Results of Experience in the recent extended Use of Steel in Mechanism and in works of Construction.
9. The best Mode of Uniting Steel and other Metals employed in Boiler Work and other constructions, and the Effect of the Operations of Punching, Drilling, and Riveting on such Metals.
10. The Construction of Warehouses and other buildings for storing Goods, with the Special View of resisting Fire, and the relative Merits of stone, brickwork, iron, and timber for that object.
11. Road-making, with special reference to the Methods adopted in large Towns, or where the traffic is heavy, including a

Comparison of the First Cost, Maintenance, and Durability of the different systems.

12. The different systems of Sinking Wells for Foundations in gravel and sandy river beds, and the best mode of obtaining foundations where the sand extends to depths of from 60 feet to 80 feet.
13. The arrangements for Erecting large numbers of Girders, of from 100-feet to 200-feet span, over rivers whose beds are almost dry for one-half the year, and are flooded for the remainder of the year.
14. The Design and Construction of Masonry Dams of great height for retaining water in Reservoirs.
15. The Storage and Filtration of Water, both natural and artificial.
16. The Distillation of Water for drinking purposes.
17. The Constant Service of Water Supply, with special reference to its introduction into the Metropolis, in substitution for the Intermittent System.
18. The Design, generally, of Iron Bridges of very large span, for Railway traffic.
19. Dock Gates and Caissons, including a Description of the requisite external and internal arrangements, with recent practical examples.
20. The Design and Construction of Building-slips for large Vessels.
21. Percussive and other Rock Drills.
22. The Appliances and Methods used for Tunnel-driving, Rock-boring, and Blasting, in this country and abroad, with details of the cost and of the results attained.
23. A History of any Fresh-Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works that may have been executed upon it, and of the effect of the works.
24. The relative Value of Upland and of Tidal Waters in maintaining rivers, estuaries and harbours.
25. The different Systems of the Towage of Vessels.
26. The Causes limiting the Speed of Railway Trains, and the possibility and probability of removing those causes.
27. A description of existing Railway Breaks, with the Motive Power employed in their Application, and the comparative results which have hitherto been obtained.
28. The Construction of Steam Boilers adapted for very High Pressures.

29. The best practical Use of Steam in Steam Engines, and the effects of the various modes of producing Condensation.
30. The Results of Experiments on Steam Jacketing.
31. The Modern Construction of Marine Engines, having reference to Economy, by Superheating, Surface Condensation, High Pressure, great Expansion, &c.
32. The Construction of Portable Steam Engines, or other Motors, of very light weight, suitable for light boats, aerial machines, &c.; and on Condensing with Air.
33. The relative advantages of different classes of Steam Engines for the performance of given work, for example: the comparative merits of Cornish Engines and Direct-action Engines for pumping water from a Mine.
34. The relative Cost of the Conveyance of Coal by Rail and by Steamer, and the best mode of loading and unloading to diminish breakage.
35. The various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency.
36. The employment of Wind and Water as Motive Powers, their relative advantages and disadvantages compared with Steam Power, and the Motors most suitable for utilising them in the best manner.
37. The Use of Gas as a Moving Power.
38. Compressed Air as a Motive Power, particularly as applied to Machinery in Mines and to Locomotives in Tunnels, with some account of its application on the Continent.
39. The best Methods of Removing Grain in bulk from a Ship to a Warehouse, of distributing in the Warehouse, and of storing grain in bulk.
40. The Manufacture of Mineral Oils, and the Lamps best adapted for their consumption in dwellings and lighthouses.
41. The 'Output' of Coal in the United Kingdom, as compared with that of other countries, illustrated by statistical tables, plans, and diagrams, showing where Coal is produced, and where and how it is consumed.
42. The Sinking to, and the Machinery applied at, deep Coal Mines (in Saxony, for instance), with a notice of the modifications necessary in future Coal Mining Operations suggested (or indicated) by the working of deep sinkings.
43. The appliances used in different countries for Dressing the Ores of Lead, Copper, Zinc, and Tin, and the Smelting of such Ores, with details of the results and cost by various methods.

44. The Appliances and Processes for the manufacture of Patent Fuel, in Great Britain and abroad, especially in France.
45. Coal Winning and Quarrying without Explosives.
46. A Comparison of the different Modes of transmitting Power for auxiliary purposes on board Ships, and in Shipyards, and Engine Factories.
47. On recent Progress in Telegraphy, including a notice of the theoretical and practical data on which that progress has been based; with some account of the improvements in the construction of land and sea lines and in the working instruments.

Instructions for Preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. A concise abstract must accompany every Paper.

Two series of illustrations are required for every Paper accepted for reading. One set of Wall Diagrams, sufficiently large and boldly coloured, so as to be clearly visible when suspended in the Theatre of the Institution; and a set of drawings on tracing paper, to as small a scale as is consistent with distinctness, ready to be engraved for insertion in the "Proceedings." The Wall Diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The communications must be forwarded to the house of the Institution, No. 25, Great George Street, Westminster, S.W., London, where any further information may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, S.W., London.*
August, 1876.

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It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1st, 1875, AND NOVEMBER 30th, 1876.

AUTHORS.

Adams, W. A. No. 1,472.—Railway Rolling Stock Capacity in relation to the Dead Weight of Vehicles. With a series of Diagrams. (Minutes of Proceedings, vol. xlvi., p. 100.)

Anderson, W. No. 1,491.—Experiments and Observations on the Emission of Heat by Hot-Water Pipes. With 7 Diagrams and 1 Table.

Barber, E. S. No. 1,493.—Gantalawa Tank, Ceylon. With 5 Drawings.

Bell, H. No. 1,501.—The Rajpootana State Railway. With 1 Tracing.

Boult, J. No. 1,497.—An Inquiry into the Source of Water in the New Red Sandstone.

Bourne, W. T. W. No. 1,471.—The Wardha Valley Coal Field, Central India.

Browne, W. R., M.A. No. 1,476.—On the Construction of Railway Wagons; with special reference to Economy in Dead Weight. With Diagrams. (xlvi., 81.)

Clark, D. K. No. 1,486.—The Evaporative Performance of Steam Boilers. (xlvi., 242.)

Conder, F. R. No. 1,503.—On the Unit of Railway Cost.

Dolson, E. No. 1,487.—On the Works for the Geelong Water Supply, Victoria. With 6 Drawings and 4 Photographs.

Duer, S., B.Sc. No. 1,468.—Hydraulic Canal Lift at Anderton, on the River Weaver. With 2 Drawings and 1 Photograph. (xlv., 107.)

Evans, J., F.R.S. No. 1,478.—On the Percolation of the Rainfall on Absorbent Soils. (xlv., 208.)

Hargrave, C. T. No. 1,480.—On the Main Roads of South Australia. With 4 Drawings.

Hutchins, G. A. No. 1,484.—The Rio Cobre Irrigation Project, Jamaica.

Keating, E. H. No. 1,492.—Hydraulic Tables applicable for Water Pipes and Sewers.

Lambert, H. No. 1,502.—The Alexandra Bridge, Punjab Northern State Railway.

AUTHORS.

Lucas, J. No. 1,461.—The Chalk Water System. With a series of Diagrams. (*Ante.*)

Macdonald, A. No. 1,469.—Repairs and Renewal of Rolling Stock. With Diagrams.

Mallet, R. T. No. 1,498.—On the Ravi Bridge. With Diagrams.

Mann, I. J. No. 1,485.—The Testing of Portland Cement. (*Post.*)

Marten, E. B. No. 1,490.—Steam Boilers. With a series of Diagrams.

Moore, B. T., M.A. No. 1,481.—On a Current Meter, a Deep Sea Current Indicator, and an Improved Ship's Log. With 5 Drawings. (xlv., 220.)

Phillips, D. No. 1,483.—The Peninsular and Oriental Steam Navigation Company's Works, Bombay. With 6 Drawings.

Phipson, W. W. No. 1,465.—The Heating and Ventilating Apparatus of the Glasgow University.

Redgrave, G. R. No. 1,474.—Sewage Interception Systems, or Dry-Sewage Processes. With a series of Diagrams. (xlv. 130.)

Redman, J. B. No. 1,495.—The River Thames.

Robinson, H. No. 1,500.—On the Transmission of Power by Water Pressure and other Motors. With Diagrams.

Shelford, W. No. 1,475.—The Treatment of Sewage by Precipitation. With Diagrams. (xlv., 144.)

Swift, L. No. 1,460.—Observations on certain Experiments to determine the Friction on Propeller Shafts of Screw Ships.

Symons, G. J. No. 1,464.—On the Floods in England and Wales during 1875, and on Water Economy. With Diagrams, Maps, and Tables. (xlv., 1.)

Target, F. No. 1,488.—On the Main Drainage of Paris and the Utilisation of its Sewage. With Diagrams.

Thomas, W. H. No. 1,477.—Hydraulic Apparatus for Loading Minerals from Railway Wagons into Ships. With 4 Drawings. (xlv., 217.)

Unwin, W. C., B.Sc. No. 1,463.—Investigation of the Motion of Light Carriers in Pneumatic Tubes when the Air is in continuous or permanent Motion. (xliii., 263.)

Unwin, W. C., B.Sc. No. 1,486.—On the Resistance of Boiler Flues to Collapse. (xlvi., 225.)

Watkins, S. No. 1,494.—On the Use of Steam in Steam Engines;

AUTHORS.

with Notes on some of the Methods of producing Condensation of the Steam exhausted from Stationary Engines. With 13 Diagrams.

Williams, R. Price. No. 1,479.—On the Permanent Way of Railways. With a series of Diagrams. (xlvi., 147.)

Wilson, A. No. 1,466.—On the Closing of the Toombuddra Ancient Breach.

Wilson, Wilberforce. No. 1,499.—The Cosmopolitan Docks at Hong Kong. With 4 Drawings.

LIST OF DONORS TO THE LIBRARY.

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BELGIUM.

Annales des Travaux publics de Belgique. *Bruxelles*

Annuaire de l'Association des Ingénieurs sortis de l'École de Liége. *Liége.*

Bulletin de l'Académie royale des Sciences de Belgique. *Bruxelles.*

Mémoires couronnés publiés par l'Académie royale de Belgique. *Bruxelles.*

CANADA.

Canadian Journal of Industry, Science, and Art. *Toronto.*

FRANCE.

Annales de Chimie et de Physique. *Paris.*

Annales des Conducteurs des Ponts et Chaussées. *Paris.*

Annales des Mines. *Paris.*

Annales des Ponts et Chaussées. *Paris.*

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Annales du Conservatoire des Arts et Métiers. *Paris.*
Annales du Génie civil. *Paris.*
Annales industrielles. *Paris.*
Annales télégraphiques. *Paris.*
Bulletin de la Société de l'Industrie minérale. *St. Etienne.*
Bulletin de la Société d'Encouragement. *Paris.*
Bulletin de la Société industrielle de Rouen. *Rouen.*
Bulletin de la Société industrielle de St. Quentin. *St. Quentin.*
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Compte rendu de la Société technique de l'Industrie du Gaz en France. *Paris.*
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Écho des Mines et de la Metallurgie. *St. Etienne.*
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Mémoires et Compte rendu de la Société des Ingénieurs civils. *Paris.*
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Nouvelles Annales de la Construction. *Paris.*
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GERMANY.

Abhandlungen der Akademie der Wissenschaften. *München.*
Annalen der Physik und Chemie. *Leipzig.*
Bayerisches Industrie- und Gewerbe-Blatt. *München.*
Berg- und hüttenmännische Zeitung. *Leipzig.*
Bulletin de la Société industrielle de Mulhouse. *Mulhouse.*
Civilingenieur, Der. *Leipzig.*
Deutsche Bauzeitung. *Berlin.*

Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege. *Braunschweig.*

Dingler's Polytechnisches Journal. *Augsburg.*

Journal für die reine und angewandte Mathematik. *Berlin.*

Journal für Gasbeleuchtung. *München.*

Mittheilungen des Artillerie- und Genie-Wesens. *Berlin.*

Mittheilungen des Gewerbe-Vereins für Hannover. *Hannover.*

Notizblatt des Architekten- und Ingenieur-Vereins für Niederrhein und Westfalen. *Köln* and *Leipzig.*

Organ für die Fortschritte des Eisenbahnwesens. *Wiesbaden.*

Protokolle des Sächsischen Ingenieur- und Architekten-Vereins. *Dresden.*

Verhandlungen des Vereins zur Beförderung des Gewerbfleisses. *Berlin.*

Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover. *Hannover.*

Zeitschrift des Bayerischen Architekten- und Ingenieur-Vereins. *München.*

Zeitschrift des Vereines Deutscher Ingenieure. *Berlin.*

Zeitschrift für Bauwesen. *Berlin.*

Zeitschrift für das Berg-, Hütten- und Salinen-Wesen. *Berlin.*

Zeitung des Vereins Deutscher Eisenbahnverwaltungen. *Berlin.*

HOLLAND.

Tijdschrift van het Koninklijk Instituut van Ingenieurs. *s'Gravenhage.*

HUNGARY.

A magyar mérnök és épitész-egylet közlönye. *Pest.*

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Journal and Proceedings of the Asiatic Society of Bengal. *Calcutta.*

Professional Papers on Indian Engineering. *Roorkee.*

ITALY.

Atti del Collegio degli Ingegneri ed Architetti in Milano. *Milano.*

Atti della Società degli Ingegneri e degli Industriali di Torino. *Turino.*

Giornale del Genio civile. *Roma.*

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Memorie del Reale Istituto Lombardo. *Milano.*
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Rendiconti del Reale Istituto Lombardo. *Milano.*
Rivista marittima. *Roma.*

NEW SOUTH WALES.

Transactions of the Royal Society of New South Wales. *Sydney.*

NEW ZEALAND.

Transactions and Proceedings of the New Zealand Institute. *Wellington.*

PORTUGAL.

Revista de Obras publicas de Lisboa. *Lisboa.*

RUSSIA.

Journal of Mines. *St. Petersburg.*
Journal of the Ministry of Ways and Communications. *St. Petersburg.*
Notizblatt des technischen Vereins zu Riga. *Riga.*

SCANDINAVIA.

Ingeniörs-Föreningens Förhandlingar. *Stockholm.*
Jernbanebladet. *Stockholm.*
Jernkontorets Annaler. *Stockholm.*

SPAIN.

Revista de Obras públicas. *Madrid.*
Revista minera. *Madrid.*

SWITZERLAND.

Bulletin de la Société vaudoise des Ingénieurs et des Architectes. *Lausanne.*
Compte rendu de la Société suisse des Ingénieurs et Architectes. *Genève.*
Eisenbahn, Die. *Zürich.*

UNITED STATES.

American Journal of Science and Arts. *New Haven.*
Engineering and Mining Journal. *New York.*

Engineering News. *Chicago.*

Journal of the Franklin Institute. *Philadelphia.*

Proceedings of the American Academy of Arts and Sciences. *Boston.*

Smithsonian Contributions to Knowledge. *Washington.*

Transactions of the American Institute of Mining Engineers. *Easton.*

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Transactions and Proceedings of the Royal Society of Victoria. *Melbourne.*

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SECT. II.—OTHER SELECTED PAPERS.

No. 1,455.—"On the Conditions of Resistance of Swing Bridges." By JULES GAUDARD, Civil Engineer, Professor at the Academy of Lausanne. Translated from the French by L. F. VERNON-HARCOURT, M.A., M. Inst. C.E.

THE Author intends specially to investigate the conditions of resistance of swing bridges, but considers it advisable, in the first instance, to make some general observations on the types commonly employed, illustrating them by examples.

There are several varieties of movable bridges. For instance, there are bridges of boats, and platforms supported by floating timbers, thus avoiding the difficulties of foundations. Sometimes a single bay is made movable so as to open a passage for vessels navigating the river; in some rare instances, the whole of the construction can be removed and placed in safety in a dock during the breaking up of ice, or in charge of the states bordering on the river in the event of war. Again, dock caissons serve as ordinary fixed bridges when once in place, and they are readily removed each time that the entrances which they close have to be opened. There are also ferry bridges, which, shorter than the space to be traversed, have to convey the load across; train ferries, steam ferries, and floating railways. In a few instances the ferry bridge rests on the bed of the stream instead of floating, and moves on rollers; of this the roller bridge of St. Malo[1] is an example. Another type of bridge has a platform resting on fixed supports, which slides out of place to allow vessels to pass, or to stop the way; but this form is rarely adopted now, on account of the difficulty of working, and of the inconvenience of the shifting platform, which is usually required for covering over the gap left in the bridge recess, sliding backwards or forwards like a drawer, and guided by rollers. At the Leven bridge,[2] the movable bay is lowered and drawn under the fixed platform. In other cases the movable bay is withdrawn by raising it vertically, and is balanced by weights descending into wells, so that a considerable mechanical work for lifting it is dispensed with, of which the vertical lift bridge over the Grand Surrey Canal[1] is an instance. Again, movable bridges rise vertically in turning on a horizontal axis, such as the wooden drawbridges of ancient fortresses, old bridges on canals, and counterpoised bridges, such as the one at Hull, with a tail-end, serving as a balance-weight, which sinks into an underground chamber whilst the drawbridge rises; the underground recesses, however, require to be kept dry by frequent pumping, and the drawbridges sometimes, when only partially raised, catch the yards of passing vessels. Lastly, other bridges turn round a quarter of a circle on a vertical axis, so as to come parallel to and within the line of the side-walls of the canal each time that a vessel requires to pass. This is the type of bridge generally adopted on canals and in docks, as, if properly constructed, only a small amount of labour is required for turning them; and the beams of a drawbridge and the well of a counterpoised bridge are dispensed with. It is of this latter class of bridges alone that the Author proposes to treat in the present communication; and even amongst these there is a certain diversity of type. On rivers whose breadth considerably exceeds the requirements of navigation, and where a central pier does not present too great an obstacle, swing bridges with double spans are naturally erected, affording two equal openings to vessels passing either way (Plate 5, Figs. 1, 2, and 3). On the other hand, in harbour entrances or canals the width is too nearly adapted to the requirements of the case to allow of this double opening, entailing as it does a central pier, and the entire space has to be set free for vessels. But this can be accomplished in two ways: either by adopting a bridge in one span, turning on one of the abutments by means of a single gearing, or by making the bridge in two half-bays joining in the centre of the span, each portion being turned on either bank by an independent gearing. This last plan is the most complicated, but it may be necessary to keep down the weight of the girders if the span is very great, as in the case of the bridge at Brest (Plate 5, Fig. 7), or for shortening the girders if the available side quay space is too small to receive a long bridge when open; or for the rotation in a quadrant of a proportionately long tail-end.

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[1] "Annales des Ponts et Chaussées," July 1874.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 442.

The material employed in the construction will, moreover, somewhat influence the choice of design. Wrought iron, from its comparative lightness in proportion to its strength, admits of spans which, with cast iron or wood, would be difficult of attainment. The Americans, indeed, do not hesitate to construct bridges of large span with wood;[1] but wrought iron is taking the place of cast iron and wood, especially for the structures under consideration, which, more than any others, require strength combined with lightness. Largeness of span is generally now considered desirable, and with this object in view, it has been suggested that the substitution of steel for wrought iron would constitute a fresh step in advance. On the canals in Holland, in olden times, numerous wooden drawbridges existed, but the injuries caused by shocks, and the wear and tear of working, rendered frequent repairs necessary, and this, added to the increasing difficulty of procuring timber large enough for the principal beams, has led to the repairs being now made with iron.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 303.

Whilst the swing bridges with two spans (Plate 5, Figs. 1, 2, and 3) balance themselves when open on account of the symmetry of their construction on each side of the central point of support; swing bridges over a single opening, whether the space is crossed by a single span, or by two half-spans from opposite sides, must be balanced on the other side of the axis of rotation by a prolongation called a tail-end. Sometimes the tail-end is as long as the portion over the opening (Plate 5, Fig. 4); but generally it is shorter, to economise materials and space, and then it must be loaded with kentledge. A weight of kentledge just sufficient to counterbalance the excess of weight of the opening span suffices where the opening span is in one piece, so that when the bridge is closed it rests on the farther abutment, and is therefore properly supported when subjected to the rolling load, and the bridge, whilst being swung, is secured from rocking by a ring of rollers. If, however, each girder spans only half the opening, or if, on account of the nearness of the pivot to the face of the wall, or for any other reason, it is not possible to guide the bridge by a ring of rollers, it is advisable to put on an excess of counterpoise in order to secure the bridge against overbalancing whilst being swung, or when subjected to the maximum load, and to insure a certain amount of pressure on the rollers, at the extremity of the tail-end of the bridge, guiding the motion. The pivot and the rollers are merely employed as means of turning the bridge, and consequently, when this function has been discharged, the tail-end is lifted by wedges or screws, so that the bridge may be raised off the rollers, and to a sufficient extent to insure a perfect bearing on the farther abutment. The pivot may be used as a support, but generally it is better to make the bridge rest on bearings nearer the edge of the abutment, so as to diminish the length of the span (Plate 5, Fig. 6).

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 205.

Many bridges are worked solely by manual labour, as there is only the friction of the machinery, the sliding friction on the pivot, and the rolling friction of the supporting and guiding rollers to overcome. When, however, the weight of the bridge is considerable, and the roller ring large, the friction of the rollers and of the complicated rack movements is so much increased, that the rate of rotation has to be reduced to render the working possible. The sliding friction is small, on account of the very small space through which the pivot moves, and by dispensing with rollers, and concentrating all the weight of the carefully balanced bridge on the pivot alone, which rests on a socket, A, and passes through a cast-iron bearing girder, B (Plate 5, Fig. 4), the bridge can be worked, without gearing, by one man, a great advantage being gained by the large amount of leverage, and the friction being considerably reduced by being confined to the central pivot. Large bridges require rollers to maintain them in position; but as these bear very little of the weight, they interfere but slightly with the movement of the bridge. In harbours with wide entrances, and where the constant traffic renders rapidity of motion indispensable, swing bridges, besides being supported on the pivot, are moved by hydraulic machinery devised by Sir William Armstrong, Vice-President Inst. C.E. This system of working has been adopted in England for the swing bridges at the Regent's Canal, the Millwall Docks, and Woolwich Arsenal, weighing respectively 450, 500, and 410 tons; and in France for the swing bridge at Marseilles,[1] weighing 700 tons, which can be opened in three minutes.

The bridge at Brest,[2] which cost £120,000, is worked solely by manual labour, turning on a circular bearing which rests on a solid support (Plate 5, Fig. 7). The span of the bridge is 385 feet 6 inches from centre to centre of the piers; it is divided into two half-spans, each balanced by a tail-end, 93 feet 10 inches long, weighted with kentledge of masonry. The cast-iron drum rotates on conical cast-iron rollers, and the bridge is turned by a rack arrangement working on the drum, and is moved by a capstan, of which there are two for each portion of the bridge, one only being used except in windy weather. The process of unwedging, lowering the screws, and releasing the bridge from its fastenings, and, lastly, turning it round, occupies nine men for a quarter of an hour: the mere operation of turning it round is performed by two men at each bay in eight minutes, but in stormy weather a double gang is required. The weight of the movable portion of each span being 350 tons, the friction of the rollers being reckoned at 4·4 lbs. per ton, and the distance traversed (which is a quarter of the circumference of a circle of 29½ feet diameter) being 23 feet, the work performed is 350 × 4·4 × 23 = 35,420 foot-lbs.; doubling this quantity, to allow for the friction of the machinery, and dividing by 8, the duration of the work of rotation in minutes, the result is 8,855 foot-lbs. of work done by two men in one minute. In comparing this with the work a man can perform for a short period, it must be remembered that the resistance of the wind has to be taken into account. The weight of the bridge is removed from the rollers by means of four screws acting under each drum. The top of the lever for turning the bridge bends down with a hinge, so that it can be lowered under the platform (Plate 5, Fig. 7, cross section x). The cylinders of the hydraulic press are so arranged as to allow of the removal and renewal of the rollers when worn down; and at the extremity of the tail-ends of the bridge there is a contrivance for firmly grasping the masonry of the abutments.

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[1] *Vide* "Annales des Ponts et Chaussées," May 1875, p. 413; also Minutes of Proceedings Inst. C.E., vol. xlii., p. 305.

[2] *Vide* "Annales des Ponts et Chaussées," November 1867.

The bridge cannot be regarded as an arch subjected to longitudinal pressure, as the contact of the extremities of the girders in the centre of the span is imperfect, and as the centre is too depressed, and there is no construction at the springing of the arch calculated to resist the longitudinal strain. The girders must therefore be regarded as long brackets, having to support the rolling load in addition to the dead weight; and the fastening of the extremites of the tail-ends to the masonry of the abutments is, accordingly, of great service in bearing a portion of the strains which tend to lift up the shore ends of the bridge.

The bridge at Brest was opened in 1861; it carries a roadway 16 feet 5 inches wide, and footpaths 3 feet 3½ inches in width on each side.

The bridge over the great lock (100 feet wide) at Havre (Plate 5, Fig. 6) may better be regarded as an arch than the bridge at Brest, but the difficulty of placing an abutment with sufficient accuracy for the three girders to butt against simultaneously, prevented this method of resisting the strains being taken into account, and the tail-ends are merely raised sufficiently to remove the weight of the bridge from the pivots, and to cause the bridge to rest on the edges of the abutments. The traffic on the bridge in each direction is separated by a central division along the roadway, by which all chance of collision is removed.

The bridge at the Marseilles repairing docks[1] (Plate 5, Fig. 8) has a total length of 209½ feet, and is 46 feet wide: three trellis-work girders, with curved top flanges, carry the bridge; and on one side of the central girder there is a single line of rails, and on the other side a roadway, with a footway supported on brackets outside the outer girder: the length of the portion of the bridge crossing the opening (91 feet 10 inches wide) in a single span is 126 feet. The bridge is raised and turned on an hydraulic pivot, the apparatus of which can be removed, repaired, and replaced in a very short time without disturbing the bridge, so that all chance of stoppage in moving the bridge is avoided. The three main girders are supported on a large transverse bearing girder, resting on the Bramah press, which serves as the axis for lifting and rotation. Each girder carries a roller under it near the extremity of its shore end: the three rollers are in a line parallel to the bearing girder, so that the bridge may rest equally on all three when slightly raised. This arrangement necessitates two circular roller paths, whose radii are 64 feet and 67 feet 7 inches respectively, measured from the pivot as the centre. The tail-end is secured by wedges, moved by a small special hydraulic cylinder. A circular cast-iron ring, 46 feet in diameter, with a groove in its outside face, is fixed under the bridge concentric with the pivot. In the groove a chain is placed, worked in opposite directions by two hydraulic cylinders, one serving for opening and the other for closing the bridge.[2] All the hydraulic engines are supplied with water under pressure from the engine and accumulator of the docks, 1,530 yards distant.

In the operation of turning the bridge, the tail-end is first released sufficiently from the wedges for the rollers to rest on the roller paths; the press then lifts the bridge, so that the far end of the bridge is raised from its supports, and the cylinders attached to the chain which works in the groove of the circular ring are set in motion and turn the bridge. This is all done by one man in three minutes, however hard the wind may be blowing; whereas for the Havre bridge, weighing only 120 tons, four men are required to push the tail-end.

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[1] *Vide* "Annales des Ponts et Chaussées," May 1875, p. 413; also Minutes of Proceedings Inst. C.E., vol. xlii., p. 305.

[2] There is a single cylinder at the bridge over the Ourcq canal at Villette (Paris), in which a piston works with a rod on each side, to which is fastened an end of the chain for turning the bridge, the ends of the chain cross and work on return pulleys. The water for the cylinder is obtained from the reservoirs of Ménilmontant at a pressure of about 4 atmospheres.

The kentledge of the Marseilles bridge is so placed as to throw 15 tons, out of the total weight of 700 tons, on the guiding rollers, to insure the stability of the bridge whilst being swung. The press, which is of wrought iron, 1 foot 11 inches internal diameter, and 6·3 inches thick, is fastened by keys into a cast-iron case, from which it is readily withdrawn for repairs as soon as the pivot is released from the water-pressure.

The prismatic top of the piston of the press is inserted in a bearing plate fixed to the bottom of the bearing girder, which has three web plates: its surface of contact is made slightly convex, or with a very obtuse bevel, so that the bridge may always have a good bearing on the axis, notwithstanding slight displacements in the process of raising. A horizontal sector is fastened to the head of the piston, which rests against two rollers with light movable axles, supported by a cast-iron bracket to counteract the lateral strain caused by the chains in turning the bridge. It was impossible to place rollers all round the piston, as it requires a certain amount of play during the wedging up of the bridge.

The ordinary water-pressure at the Marseilles docks, amounting to 52 atmospheres, is amply sufficient for working the cylinder, 13·8 inches in diameter, for wedging up the bridge; and also the two conjugate pistons, for swinging the bridge, whose diameters are 11·8 inches, and their length of stroke 9 feet 2¼ inches, which is supplemented by a system of multiplying pulleys. In the case however, of the press for lifting the pivot, which, with a diameter of 1 foot 11 inches, has to support a weight of 700 tons, the water-pressure required is equal to 250 atmospheres; this increase of pressure is obtained by a double-acting force-pump which, receiving a supply of water at the ordinary pressure of 52 atmospheres, raises it to five times that pressure. M. Barret, the engineer who designed the bridge, considers that, owing to the great advance in metallurgy and casting, it would be feasible to make the press with an internal diameter of 4 feet 11 inches, and thus dispense entirely with auxiliary apparatus for increasing the normal water-pressure.

The leather lining makes a water-tight joint with the piston; but in order to prevent its tendency to tear from the turning strain imparted by the adherence of the rotating pivot, the interstice between the edges has been fitted with a band of india-rubber, which, by the interior adhesion it gives to the opposite edges of the leather, causes its exterior surface to slide on the metal. When in the act of turning, the motion of the bridge becomes a little too accelerated; the moment of inertia of the large mass is only partially restrained, owing to the imperfect elasticity of the hydraulic cushion, and consequently it was found necessary to modify the slide-valves regulating the water supply, so that, whilst not liable to be opened by each stroke of the ram, a regulating counter-pressure might obviate the jerks that would otherwise occur.

The Author is inclined to think that the employment of the hydraulic machines for wedging up the bridge is superfluous, and that the fall of the pivot, after it has been raised for lifting the bridge from its supports at its extreme end, might be utilised to insure the proper pressure of the bridge on three points of support, fixed once for all at suitable levels. This is, indeed, the opinion of M. Barret, for he says that if he had to construct another similar bridge he would dispense with the apparatus and cylinder for wedging up the bridge; that he would retain the three rollers, weighted with the slight load of 5 tons apiece; that he would make the roller supports movable in a vertical line, and so balanced with counterpoises that the rollers should always be kept in contact with the roller path, whilst the bearing girder lifts both extremities of the bridge off their supports. The top of the pivot, instead of being rounded off, could be made quite flat; and, in place of only two horizontal rollers to steady the pivot on the side where the pull of the turning chains takes place, there could be a set of rollers encircling the pivot. M. Barret considers that by introducing the improvements suggested, a bridge over 2,000 tons in weight might be turned with perfect safety in three minutes.[1]

The examples referred to suffice to illustrate, in a general way, the types of swing bridges usually constructed at the present day.

The Author now proposes to investigate the conditions of resistance of swing bridges. In the first place, it is necessary to draw a distinction between the swing bridges having two half-spans, and those formed in one piece. Whereas the latter when closed have a firm bearing on the farther abutment, the two spans of the others only reach the centre of the opening, and even when firmly butting against each other can only afford a horizontal reaction, which is injurious in a straight beam, and could only be of service if the girders, made in the form of an arch, rested at their springing upon very solid abutments.

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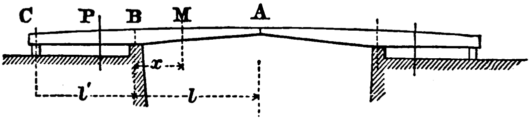
[1] The Marseilles bridge rests on its pivot by superposition, a simpler system than that followed by the Dutch engineers, who hang their bridges by the cast-iron pin, placed over the pivot, by means of a circular row of large and strong bolts. At the Dordrecht bridge, there are only three bolts, of steel, being not less than 7 inches in diameter.—*Vide* "Notice sur les Travaux publics en Hollande," par Ph. Croizette Desnoyers. Paris, 1874.—J. G.

The bridge formed with two spans shall first be considered.

In the absence of a mutual support at A (Fig. 1), each span, B A, must be regarded as a simple bracket, fixed to the side-wall by reason of being counterbalanced by the tail-end, B C, carrying the counterpoise. The counterpoise at C, having to keep in equilibrium the bridge when weighted with the maximum load, as well as the bridge itself, generally throws a considerable excess of weight on the rollers on which the bridge turns, and consequently increases the work of swinging the bridge. At Brest the case is different, for the movable load is counterpoised by fastening the tail-end to the solid masonry when the bridge is closed, and in turning the bridge the balancing of the dead weight alone has to be dealt with.

FIG. 1.



The theory of the resistance of two half-spans not butting against each other presents no difficulty. If the pivot, P, is one of the points of support of the bridge when closed, it is evident that the maxima moments of flexion are necessarily produced by the action of the full load; but as it is generally advisable to remove the weight off the pivot and rollers by lifting the extremity, C, of the tail-end with wedges or screws, to bring the bearing on to B, the edge of the side-walls, the length of the bracket is reduced to B A when loaded, and is P A when unloaded and being swung round; and it accordingly may happen that the reduction in length may more than compensate for the increase in weight.

Let q be the load for a unit of length on the portion B A of the bridge whose length is l, and q' on the portion B C whose length is l'. The maximum bending moment at B will be $\frac{q\,l^2}{2}$ with the bridge closed, and the variable moment μ for a section M, with abscissa x and B the origin of co-ordinates, will be $\mu = \frac{q}{2}(l - x)^2$. The moment of the portion B C supported only at B and C must, in order to maintain equilibrium, be equal to $\frac{q\,l^2}{2}$, and for this purpose a counterpoise is usually added. This condition being fulfilled, the equation for the moment μ' of the portion B C, the abscissa x' having its origin at B and being measured along B C, will be

$$\mu' = \left(q\frac{l^2}{l'} - q'\,x'\right)\frac{l' - x'}{2}.$$

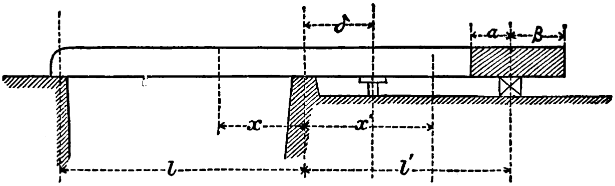
The reaction at C is $\frac{q'\,l'}{2} - \frac{q\,l^2}{2\,l'}$, neglecting the counterpoise, the object of which is to prevent the reaction ever becoming negative. The force required for wedging up the bridge will be this reaction, with the dead loads substituted for q and q', increased by the weight of the counterpoise. Similar formulæ would give the resistance of the bridge when open, the origin of co-ordinates being transferred from B to P. The greatest strains being produced at B and P, the girder must be strengthened at these points and lightened at the ends, especially as this form of equal resistance will not affect the distribution of the forces directly the bridge rests on only two supports.

Considering briefly the case where the horizontal thrust at the centre of the span when the bridge is shut is utilised by treating the bridge as an arch, it must be assumed that the under side of the bracket, B A (Fig. 1), is formed in a half arc of sufficient rise, and that the lifting at C not only releases the pivot and rollers, but turns over the part B A on the support B, at the edge of the side-wall, till the requisite thrust is produced at the extremity, A, of the half-span. The bridge will thus be placed in the condition of an iron arch, provided the side-walls resist the thrust; and the portion B C must be regarded as a girder fixed to the masonry at B and merely supported at C. The object of raising the bridge at C is to develop the thrust due to the dead weight. Let w be the weight for a unit of length, then the thrust is given by the simple approximate formula $\frac{w\;l^2}{2\,r}$, r being the rise of the arch: the force required at C to produce it is $\frac{q\,l^2}{2\,l'}$ in addition to the force which sufficed in the preceding case. In fact, the counterpoise and half the weight of the portion B C, turning on the support B, has to be lifted just as if the portion B A was not there, for the moment tending to overturn this latter portion is supported by the counter-thrust of the other half-span. To obtain a thrust against the side of the abutment hinged struts have been sometimes employed (Plate 5, Fig. 5), which are let down by chains when the bridge is closed, so as to make them rest against their bearings, but this system appears to have been abandoned as too complicated an operation for frequent adjustment.

RESISTANCE OF A SWING BRIDGE OF SINGLE SPAN.

By the term bridge of single span is intended a bridge crossing the entire opening in one piece, and it accordingly includes the case of symmetrical bridges having two spans balancing each other and crossing two openings, as each of these spans may be considered as the tail-end of the other. In these bridges the central support is exactly in the centre of the bridge, and coincides with the pivot on which the bridge turns, and evidently is a particular instance of the more general case in which the bridge does not rotate on its central point and requires a counterpoise to adjust it, and where the intermediate support on which the bridge rests when closed is at a certain distance, δ (Fig. 2), from the pivot.

FIG. 2.



When the bridge is open and placed on the side-wall it can be supported by a slight wedging at any point, as the strains are at their minimum. During the rotation, however, the bridge is entirely supported on the pivot, assisted in some cases by the ring of rollers. The bridge having the span $l + \delta$, and weighing w per unit of length, is subjected, at the point whose abscissa is $\delta + x$ (taking the pivot as the origin, and x the distance from the point of support on the side-wall), to the bending moment $\mu = \frac{w}{2}(l - x)^2$, the equation to a parabola whose axis is vertical, whose parameter is $\frac{2}{w}$, and its vertex at the extremity of the span.

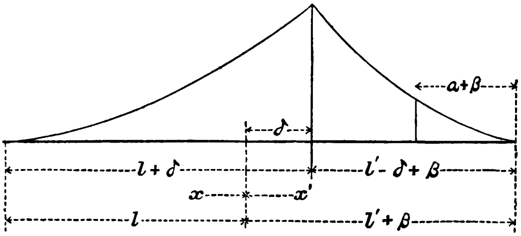
The maximum moment at the pivot, where $x = -\delta$, is $\frac{w}{2}(l+\delta)^2$. With regard to the tail-end, it is of primary importance to weight it sufficiently to prevent the bridge upsetting whilst being swung. If the length of this portion was precisely $l' - \delta$, and the kentledge could be concentrated in one point at the extreme end, and assuming the tail-end to weigh the same per unit of length as the rest of the bridge, the weight of this kentledge would be $\frac{w}{2}\,\frac{(l+\delta)^2-(l'-\delta)^2}{l'-\delta}$, and consequently the equation of the variable bending moment, with abscissa x' measured from the side-walls, is $\mu' = w\,\frac{(l+\delta)^2-(l'-\delta)(x'-\delta)}{2(l'-\delta)}(l'-x')$, which is a parabola of less curvature than the preceding one, but with the same parameter $\frac{2}{w}$, and a vertical axis.

In practice the kentledge is generally spread over a certain length $\alpha+\beta$ (Fig. 2) on each side of the supporting rollers. Let g be the weight of the kentledge per unit of length, then, the length of the tail-end being $l'-\delta+\beta$, the weight is w per unit for a length $l'-\delta-\alpha$, and $w+g$ for the remaining length $\alpha+\beta$. The minimum value of one of the quantities g, α, β, is given by the equation

$$\frac{w}{2}(l+\delta)^2 = \frac{w}{2}(l'+\beta-\delta)^2 + g(\alpha+\beta)\left(l'-\delta+\frac{\beta-\alpha}{2}\right)$$

the condition of equilibrium for rotation on the pivot, the value of the other two being determined by the requirements of the design. The value of one of the three is always somewhat increased to insure a pressure on the rollers in the process of swinging. The bending moment of the tail-end of the bridge is represented by two parabolic arcs (Fig. 3).

FIG. 3.



From the extreme end where $x' = l' + \beta$ to the point where $x' = l' - a$ the equation is

$$\mu' = \frac{w+g}{2}(l' + \beta - x')^2,$$

and from this latter point to the pivot, where $x' = \delta$, the equation is

$$\mu' = \frac{w}{2}(l' + \beta - x')^2 + g(a + \beta)\left(l' - x' + \frac{\beta - a}{2}\right).$$

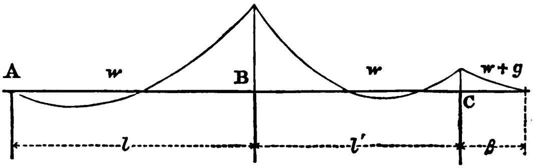
The greatest strains on the portion of the bridge near the pivot are generally produced under the conditions just considered when the bridge is being opened and supports merely its dead weight; but other parts of the girders are subjected to greater strains when the bridge is closed, wedged up and loaded.

The bridge when closed forms a continuous beam over two openings, l and l', with an overhanging piece of length β attached to the tail-end. The strain on this piece is very slight, on account of its shortness, but it produces a moment at the point of support which tends to press down the tail-end as if it were fastened to the bearing.

The Author proposes to analyse successively the strains produced by the various forces acting on the bridge; and, assuming the three points of support of the mean fibre to lie in a straight line, to calculate, first, the bending moments due to the dead weight w per unit of length and the counterpoise g; next, the moments produced by the moving load; then the changes produced by the alterations in level caused by bringing the bridge on to its proper bearings; and, lastly, by a combination of the various forces simultaneously acting, to obtain the actual strains at each point of the girder considered as having the same section throughout.

The permanent load on the bridge is w per unit of length for the portions l and l' (Fig. 4), and, neglecting the counterpoise on

Fig. 4.



the portion a, $w + g$ for β. The moment at the point C is

$\mu_2 = \frac{w+g}{2}\beta^2$; then by the theory of moments (the moment at A being zero) $\mu_2 l' + 2\mu_1(l+l') = w\frac{l^3+l'^3}{4}$, or $\mu_1 = w\frac{l^2 - ll' + l'^2}{8} - \frac{l'\beta^2}{4}\frac{w+g}{l+l'}$; and for any points along l and l', at distances x and x' respectively from B, the moments will be

$$\mu = \left(\frac{\mu_1}{l} - \frac{wx}{2}\right)(l-x), \text{ and } \mu' = \frac{\mu_2 x'}{l'} + \left(\frac{\mu_1}{l'} - \frac{wx'}{2}\right)(l'-x').$$

The reactions at A, B, and C are

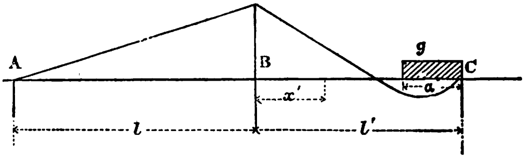
$$w\frac{3l^2 + ll' - l'^2}{8l} + \frac{\beta^2 l'}{4l}\frac{w+g}{l+l'};$$

$$w\frac{l+l'}{8}\left(3 + \frac{l}{l'} + \frac{l'}{l}\right) - \frac{w+g}{4ll'}(2l+l')\beta^2;$$

and $$(w+g)\beta\left(1 + \frac{\beta}{2l'} + \frac{\beta}{4(l+l')}\right) + w\frac{3l'^2 + ll' - l^2}{8l'}.$$

The weights, g, acting on each unit of length of a produce no moment at C (Fig. 5), but only at B; let μ_1 be the moment, and

FIG. 5.



$g\,du'$ the weight on an infinitesimal length at a distance u' from B so that $\mu_1 = \int g\,du'\,u'\,\frac{l'-u'}{2l'}\,\frac{2l'-u'}{l+l'}$; and taking the sum between the limits $l'-a$ and l' the moment is $g a^2 \frac{2l'^2 - a^2}{8l'(l+l')}$ The locus of the moments along l is a straight line, and along l' is straight from B to $l'-a$ from B, and parabolic from that point to C (Fig. 5).

The reactions at A, B, and C, due to the weight g along a, are

$$-ga^2\frac{2l'^2 - a^2}{8ll'(l+l')};\quad ga^2\frac{4ll' + 2l'^2 - a^2}{8ll'^2}; \text{ and}$$

$$ga\left(1 - \frac{a}{8l'^2}\,\frac{6l'^2 + 4ll' - a^2}{l+l'}\right).$$

The total moment, M, due to the dead load when the bridge is closed, obtained by combining the above results, is

$$\frac{1}{8\,(l+l')}\left\{w\,(l^3+l'^3)-2\,(w+g)\,l'\,\beta^2+g\,a^2\,\frac{2\,l'^2-a^2}{l'}\right\};$$

and the moment at any point at a distance x from B is

$$\left(\frac{\mathrm{M}}{l}-\frac{w\,x}{2}\right)(l-x);$$

and where $x=\frac{2\,\mathrm{M}}{w\,l}$ there is a point of inflection, beyond which point the moment becomes negative. Along the portion l' the moment due to the permanent load when the bridge is closed is equal to

$$\left(\frac{\mathrm{M}}{l'}-\frac{w\,x'}{2}\right)(l'-x')+\frac{(w+g)\,\beta^2-g\,a^2}{2\,l'}\,x'$$

between B and a distance $l'-a$ from B, and beyond this it becomes

$$\left\{\frac{\mathrm{M}}{l'}-\frac{w\,x'}{2}+g\,\frac{(l'-a)^2-l'\,x'}{2\,l'}\right\}(l'-x')+\frac{w+g}{2\,l'}\,\beta^2\,x'.$$

The strains due to the weight of the moving load on the bridge when closed must next be investigated, and combined with those due to the permanent load. The bending moments produced by the moving load are sometimes positive and sometimes negative, according to the position of the load. In order to ascertain what parts of the bridge must be loaded to obtain, at any given point, a positive or negative moment, the effect of a weight, P, acting at a single point on one or other of the two spans l and l', must be considered, neglecting the small portion of the load that might affect the overhanging end β.

When two weights, P and P′, are placed on the two spans, l and l', of a beam resting on three supports at the same level, the weights being applied at distances u and u' respectively from the intermediate support, a moment is produced which presses down the beam on this support, and whose value is

$$\frac{1}{2\,(l+l')}\left\{\mathrm{P}\,u\,(l-u)\,\frac{2\,l-u}{l}+\mathrm{P}'\,u'\,(l'-u')\,\frac{2\,l'-u'}{l'}\right\}=\mathrm{M}_1;$$

and at any point x along the length u of the span l the moment is represented by the equation

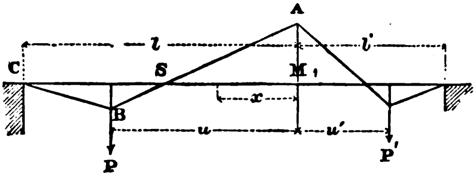
$$\mu=\mathrm{M}_1\,\frac{l-x}{l}-\mathrm{P}\,\frac{l-u}{l}\,x;$$

and from the point of application of P to C (Fig. 6) by the equation

$$\mu = \frac{l - x}{l}(M_1 - Pu).$$

These are the equations to the two straight lines AB and BC (Fig. 6). It is evident that M_1, the positive moment at the intermediate support, increases with P and P′ wherever they are placed along l and l'; and therefore the maximum strain at this point is produced by fully loading both spans, which makes $M_1 = w' \frac{l^2 - l\,l' + l'^2}{8}$, where w' is the moving load per unit of length.

Fig. 6.



It also follows that to obtain the greatest positive value of μ at any other point where $x < u$ the span l' must be always fully loaded, since M_1 is thus increased without the introduction of negative terms; but, as regards the load on the span l, for a given point at a distance x from the intermediate support the greatest effect in increasing the positive value of μ is produced by loading l from its extremity to a point where $u \overline{>} l - \sqrt{l^2 - 2\,l\,x \frac{l + l'}{l - x}}$; and when $x \geqq \frac{l^2}{3\,l + 2\,l'}$ the span l must be entirely unloaded to produce the maximum effect.

The intermediate point of support, where $x = 0$, is the only point where the moment is a maximum with both spans fully loaded.

To obtain the maximum negative value of μ at a point x the span l' must be unloaded, and the span l must be loaded between the points $u = 0$ and $u = l - \sqrt{l^2 - 2\,l\,x \frac{l + l'}{l - x}}$, where x is less than $\frac{l^2}{3\,l + 2\,l'}$, but for points beyond this distance l must be fully loaded.

The same observations are applicable to the exactly parallel case of the span l', and the same formulæ by transposing l and l'.

From the foregoing considerations it appears that the greatest positive moment produced by a load w' per unit of length, at a point in the span l at a distance x from the origin, where the value of x is between zero and $\frac{l^2}{3\,l + 2\,l'}$ is obtained by taking the sum of the moments produced by the weights $w'\,du$ within the limits $u = l$ and $u_1 = l - \sqrt{l^2 - 2\,l\,x\frac{l + l'}{l - x}}$, and by the weights $w'\,du'$ distributed all along l', which give

$$\mu = \frac{w'}{l}\int_{u_1}^{l}\left(u\frac{2\,l - u}{2\,l}\,\frac{l - x}{l + l'} - x\right)(l - u)\,du + \frac{w'}{2\,l\,l'}\,\frac{l - x}{l + l'}\int_{0}^{l'} u'\,(l' - u')\,(2\,l' - u')\,du',$$

and integrating,

$$\mu = \frac{w'}{2}\left(\frac{l^2 - l\,l' + l'^2}{4}\,\frac{l - x}{l} + \frac{l + l'}{l - x}\,x^2 - l\,x\right).$$

When x is greater than $\frac{l^2}{3\,l + 2\,l'}$ the span l' alone must be loaded to obtain the greatest positive moment, which is $\mu = \frac{w'\;l'^3}{8\,l}\;\frac{l - x}{l + l'}$ the equation to a straight line which starts as a tangent from the preceding curve at the point $x = \frac{l^2}{3\,l + 2\,l'}$.

As the positions of the loads which produce the greatest negative moments are exactly supplementary to those which give the greatest positive moments, the negative maxima may be obtained by deducting the two values just obtained for μ from the value of μ when the spans are fully loaded, which is $w'\,\frac{l - x}{8}\left(l - l' + \frac{l'^2}{l} - 4\,x\right)$, and the resulting negative maxima moments are $\mu = -\frac{w'\,x^2}{2}\,\frac{l' + x}{l - x}$, when the value of x is between zero and $\frac{l^2}{3\,l + 2\,l'}$, and $\mu = w'\,\frac{l - x}{8}\left(\frac{l^2}{l + l'} - 4\,x\right)$ between this latter point and $x = l$. The greatest negative moment is at the point where $x = \frac{l}{8}\,\frac{5l + 4l'}{l + l'}$, and its value is $-\frac{w'}{2}\left(\frac{l}{8}\,\frac{3\,l + 4\,l'}{l + l'}\right)^2$.

To obtain corresponding formulæ for the span l', it is only necessary to transpose l and l'.

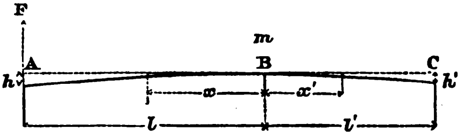
The effects of the load on the overhanging portion β have not been taken into consideration, but they would be small, and where producing any appreciable result would tend to diminish the strains on the bridge.

The results obtained for the permanent and moving loads might be combined, but the Author proposes merely to do this in a special example, as for the more general case the strains can be more simply represented by the graphic method; and moreover the curves showing the strains on the bridge when closed and when open, can be put on the same diagram.

The arbitrary strains due to wedging up the bridge remain to be considered. M. Bresse has stated[1] the general theorem of three moments, allowing for the alterations in level, that the supports may experience, but it is easy to obtain a special formula suitable to this particular case.

Let A B C (Fig. 7) be a beam spanning two openings and originally straight, but depressed at the ends A and C in a vertical direction through distances h and h', which depression produces a bending moment m at B, and a reaction F at A, and consequently at a point x in the span l, $\epsilon \frac{d^2 y}{d x^2} = - \mathrm{F}(l - x) = m \frac{l - x}{l}$, since the bending moment must equal m when $x = 0$. In the equation, ϵ is the product of the modulus of elasticity and the moment of inertia of the cross section, and the second differential co-efficient $\frac{d^2 y}{d x^2}$ of the curve of flexion expresses approximately the curvature of the mean fibre.

FIG. 7.



Integrating the equation, it becomes $\epsilon\, y = m\, x^2 \frac{3\, l - x}{6\, l} +$ and since $y = h$ when $x = l$ $c = \epsilon \frac{h}{l} - \frac{m\, l}{3}$, which gives the inclination of the mean fibre at B; and for the span l' the expression is $c' = \epsilon \frac{h'}{l'} - \frac{m\, l'}{3}$, and since the beam is continuous the inclination at B must in both cases be a tangent to the curve of deflection, and therefore $\epsilon \left(\frac{h}{l} + \frac{h'}{l'}\right) = m \frac{l + l'}{3}$, and supposing all the displacement to occur at C it becomes $\epsilon \frac{\mathrm{H}'}{l'} = m \frac{l + l'}{3}$.

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[1] *Vide* "Mécanique appliquée." M. Bresse. Vol. iii., p. 6.

When C is raised a height H' a negative moment m is produced at B which reduces the positive moment at B, caused by the load, by an amount $\frac{3\epsilon}{l'}\frac{H'}{l+l'}$. This involves a special lifting force at C, whose value is $\frac{3\epsilon}{l'^2}\frac{H'}{l+l'}$, in addition to the reaction at this support when kept level with the two other supports.

The reaction at C due to the dead weight, which is the only load acting before it is raised, is

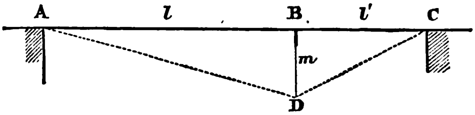
$$Q' = \frac{w\,l'}{2} + (w+g)\,\beta + g\,a\,\frac{2\,l' - a}{2\,l'} + \frac{\mu_2 - \mu_1}{l'},$$

where μ_1 and μ_2 are the moments due to the permanent load.

In raising the extremity C it is first necessary to exert a force Q', by means of the wedges or screws, which causes the deflection near the pivot to disappear, and then an additional pressure, $\frac{3\epsilon}{l'^2}\frac{H'}{l+l'}$, to raise it the height H'. The total distance through which C is raised is $H' + Q'\,l'^2\,\frac{l+l'}{3\epsilon}$, or calling the total force exerted Q'' the total distance traversed is $l'^2\,\frac{l+l'}{3\epsilon}\,Q''$.

The bending moments caused by the wedging up are represented by the straight lines A D and C D (Fig. 8), the ordinate B D representing the negative moment m at B due to raising C through a height H'. The lifting of C produces a considerable diminution in the strains near the central support when the bridge is loaded, and allowing that it is advantageous that the strains at that part should be less when the bridge is loaded than when being swung, a minimum value can be inferred for m, and consequently for H', and also Q'' which is equal to $Q' + \frac{m}{l'}$. The highest limit of the value of m is $(w + w')\,\frac{l^2 - l\,l' + l'^2}{8} - \frac{l'\,\beta^2}{4}\,\frac{w+g}{l+l'} + \frac{g\,a^2}{8\,l'}\,\frac{2l'^2 - a^2}{l+l'}$,

FIG. 8.



the value of the positive moment of the bridge when closed and its supports at the same level, as if this limit was passed the extremities of the bridge would tend to bend upwards.

If the extremity A was raised instead of C the pressure exerted would be less, but the distance traversed would be greater, so that there would be no saving in mechanical work.

Taking a special case where the length $\alpha + \beta$, over which the counterpoise is distributed, is very short, and where the distance, δ, between the pivot and the intermediate support is equal to zero,[1] the counterpoise $g\ (\alpha + \beta)$ concentrated on the support of the tail-end has the balancing effect of $w \frac{l^2 - l'^2}{2\,l'}$, and the reaction to be overcome in raising the tail-end, including the counterpoise as well as the force required to raise the end C a height H′, will be reduced to the simple expression $Q'' = w \frac{3\,l^2 + l\,l' - l'^2}{8\,l'} - \frac{m}{l'}$. The limit of the wedging up, so that the bridge when unloaded may not be lifted off the pivot or the central support, is given by the equation $m = -w \frac{l^2 + 3\,l\,l' + l'^2}{8}$; the resistance to be overcome, or Q'', is $w\,l \frac{l + l'}{2\,l'}$, and the total lift to be given to the extremity C is $\frac{w\,l\,l'}{6\,\epsilon}(l + l')^2$. The pressure on the extremity of the tail-end must at least be sufficient to prevent its rising when the other portion of the bridge alone is loaded, so the holding-down pressure when the bridge is unloaded $Q'' \geqq \frac{w'}{8\,l'} \frac{l^3}{l + l'}$.

Also the wedging-up force at C should at least suffice to prevent the strain at the central support from being greater when the bridge is closed and loaded than when it is open, and hence $Q'' \geqq w' \frac{l^2 - l\,l' + l'^2}{8\,l'}$.

In the particular case under consideration the locus of the absolute maxima moments is not influenced by the counterpoise when the bridge is closed, which simplifies the algebraic solution. The total strains due to w, w', and the wedging are obtained from the following values of the moments. Between $x = 0$ and $x = \frac{l^2}{3l + 2l'}$, along l the maximum moment μ is

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[1] This subject has been thoroughly investigated by M. Brockhaus, and the calculations published in the "Annales des Travaux publics de Belgique," and in the "Annales du Génie civil," 1874.

$$\frac{w + w'}{2}(l - x)\left(\frac{l^2 - l\,l' + l'^2}{4\,l} - x\right) + \frac{w'\,x^2}{2}\,\frac{l' + x}{l - x} + m\,\frac{l - x}{l};$$

and beyond this point,

$$\mu = \frac{l - x}{8\,l}\left\{\frac{(w + w')\,l'^3 + w\,l^3}{l + l'} - 4\,w\,l\,x + 8\,m\right\};$$

and the minima moments, or negative maxima, are respectively between the same limits,

$$\mu = \frac{l - x}{2\,l}\left(w\,\frac{l^2 - l\,l' + l'^2}{4} - w\,l\,x + 2\,m\right) - \frac{w'\,x^2}{2}\,\frac{l' + x}{l - x};$$

$$\mu = \frac{l - x}{2\,l}\left\{\frac{w + w'}{4}\,l\left(\frac{l^2}{l + l'} - 4\,x\right) + \frac{w}{4}\,\frac{l'^3}{l + l'} + 2\,m\right\}.$$

As long as the supports maintain their original level the absolute maxima moments shift at the abscissa $\frac{l^2 - l\,l' + l'^2}{4\,l}$; up to this point the positive maxima are the only moments to be considered, and beyond it only the negative maxima.

A diagram representing the moments for a particular instance of a swing bridge (Plate 5, Figs. 9, 10, 11) has been drawn, where $l = 65 \cdot 6$ feet, $l' = 46$ feet, $\delta = 16 \cdot 4$ feet, $w = 0 \cdot 36$ ton per lineal foot, $w' = 0 \cdot 42$ ton. With $\beta = 3 \cdot 28$ feet, and $a = 13 \cdot 12$ feet, the exact balancing weight would require $g = 2 \cdot 52$ tons; but supposing g be increased to 3 tons, there would be an excess of about 8 tons, which would insure the proper action of the rollers supporting the tail-end. Considering, first, the diagrams of moments in the case of the open bridge, the equation $\mu = \cdot 18\,(65 \cdot 6 - x)^2$ gives, when $x = -16 \cdot 4$, the maximum moment at the pivot equal to 1,210.

The curve is a parabolic arc with its axis vertical, and its vertex at the extremity A. With regard to the moments of the tail-end the weight g may be taken as $2 \cdot 52$ tons, as the rest of the counterpoise is borne by the guiding rollers, and the curve of the moments is given by the equation $\mu' = \cdot 18\,(49 \cdot 21 - x')^2 + 41 \cdot 328\,(41 \cdot 08 - x')$ from the pivot, where $x' = 16 \cdot 4$ and the moment 1,210, to the point where $x' = 32 \cdot 8$, making $\mu' = 390$, and then to the extremity, where $x' = 49 \cdot 21$, there is another curve $\mu' = 1 \cdot 44\,(49 \cdot 21 - x')^2$, which is a tangent to the preceding one. When the bridge is closed the whole weight of the counterpoise must be taken, or $g = 3$ tons, as in this case it tends to increase the strains, being situated within the end support. By substituting the given values of l, l', w, w', and g in the general equations previously given, the numerical values of the other moments are similarly found; and the curves representing their values, at any point of the bridge when open, closed, and loaded, are shown on the diagram (Plate 5, Fig 11). After having drawn the portions of the curves, whether positive (above the axis of x), or negative (below the axis of x), representing the moments produced by the fixed and moving loads the effects are combined, and to the fixed ordinates due to the permanent load are added the ordinates subsequently obtained (positive or negative), which tend to increase the strains, and the results are shown by the dotted curves in the diagram. It is evident from these curves that there are only very short spaces within which the elastic curvature can change its sign, although w' considered alone always produces a positive and a negative moment. The closed bridge has been assumed to have all its supports at the same level, and this position necessitates the existence of a wedging-up force capable of neutralising the deflection of the open bridge, producing a reaction at C equal to 49 tons. The amount of lift is $\frac{4409232}{\epsilon}$, a quantity whose value depends on the moment of inflexibility, ϵ, which is afforded by the section of the girder employed. After the supports have been brought to a level the inferior limit of the additional wedging-up force is given by the consideration that the tail-end must not be liable to rise when the other portion of the bridge alone is loaded, so that Q'' must be greater than 2·9 tons; this limit, however, is considerably lower than it would be ever wise to adopt.

Again, for the superior limit the wedging-up force must not exceed 19¼ tons, in order that the bridge, when unloaded, may not be lifted off its central support, which joined to the pressure of 49 tons previously exerted gives 68¼ tons as the total force of wedging. Another superior limit is when, with the bridge loaded, the negative moment due to wedging neutralises the positive moment at the central support. This gives a force of 8¼ tons, which joined to the previous pressure of 49 tons makes the limiting force 57¼ tons. Within these limits the wedging-up force may be fixed as desirable. For instance, if the most advantageous wedging force for the bridge when closed is required (leaving out of consideration the strains on the bridge when open), by taking the broken line A B′ C, instead of the straight line A B C, as the axis from which to measure the ordinates, the maximum positive moment on the support B will be made equal to the maximum negative moment F G. The moment of wedging, B′ B, satisfying this condition is about 77, and consequently the reaction of 49 tons has only to be increased by $\frac{77}{46} = 1\frac{2}{3}$ ton, so that the whole force is $50\frac{2}{3}$ tons. The space D E, in which, with the old axis, the curves were liable to change signs, is reduced to D′ E′.

It would appear at first sight useless to endeavour to reduce somewhat the strains on the bridge when closed, since in the example given they are considerably less than when the bridge is open, in which latter case the moment is 1,210 over the pivot. In consideration, however, of the disproportion between the two kinds of strains, exaggerated in the example by reason of the distance 16·4 feet between the pivot and the support B of the bridge when closed, it appears desirable to support the strains by two separate means. In the first case, where the bridge is closed, the ordinary resistance of the wrought-iron plate girder to flexion would bear the strain; and in the second case, where the bridge turns on the pivot and rollers, a tension-bar, or suspension-chain, would be used as represented in the bridge (Plate 5, Fig. 9) which serves as the example, and which is a copy of the bridge at Birkenhead.[1] Assuming that t is the tension of the rod when the bridge is open, and that its perpendicular distance from the central point of the girder is 19·68 feet, as shown on the drawing (Plate 5, Fig. 9), it follows that the rod produces, with reference to the pivot, a negative moment $-19 \cdot 68\ t$, by the help of which the bending moment exerted on the girder when the bridge is open can be reduced to the limited amount which exists when the bridge is closed. For this purpose, taking on the diagram a length N O = L B′ = 300 approximately, measured from N the end of the ordinate corresponding to the pivot, the remaining portion O P = 910 being made equal to the auxiliary moment $19 \cdot 68\ t$ gives the tension required. By drawing, moreover, the line A O on the diagram, the parabola A Q N will still represent by its vertical ordinates the bending moments of the swinging portion of the open bridge, but the ordinates must be measured from the new axis A O instead of from the horizontal axis A B, so that between A and Q the curve will be negative.

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[1] Another instance is furnished by the bridge over the river Wensum on the Norwich railway: *vide* Minutes of Proceedings Inst. C.E., vol. v., p. 434.

A force of longitudinal compression, equal to the horizontal projection of t, will be added to the force of flexion, but its relative value is very insignificant. The section of plate girder adopted (Plate 5, Fig. 10) has a solid web plate, and if allowed to be strained to 3·82 tons per square inch will afford a moment of resistance equal to 300, which is sufficient for the case of the bridge when closed, and also, consequently, for the open bridge when supported in the manner described above, neglecting the longitudinal compression. The value of this force is $\frac{910}{19 \cdot 68} =$ 46 tons approximately, which spread over a sectional area of 50·22 inches would increase the strain by 0·91 ton per square inch. This additional strain might easily be provided for either by adding near the pivot a short plate to the lower flange only of the girder which is in compression, or by merely raising a little the point O in the diagram, which indicates an increase in the tension on the supporting rod.

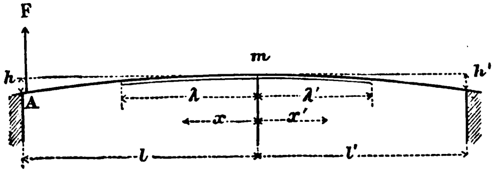
The tension-rod acts as a substitute for the support, of which the extremity of the swing portion of the bridge is deprived when open, by means of the vertical component of the tension t, which is equal to about 10 tons. As this component only slightly exceeds the reaction developed at the support at A by the unloaded bridge when closed, which is 8¾ tons when the supports are at the same level, it follows that when the wedging up has only slightly raised the end above the level the tension-rod will be quite relieved from strain, and the flexion of the whole girder when the bridge is closed will follow the laws shown on the diagram. This is based on the assumption that the section of the girder is kept constant throughout its whole length, which, moreover, is rendered advisable by the fact that the portions capable of being made less strong would be very short, as the diagram indicates. The case would be different if, instead of adopting an auxiliary method of suspension, it was desired to construct a girder capable of supporting the whole strain of the bridge when open. Suppose, for example, that a symmetrical bridge, spanning two equal openings, and turning on its central support, had to be constructed, and that, moreover, the bridge was to carry a railway, and consequently to be subjected to a relatively heavy rolling load, there would in this case be no longer such a marked difference between the limits of the strains of the bridge when unloaded and open, and when closed and loaded. The best plan in such a case would be to construct a simple girder bridge without tension-rods, but strengthened at the pivot by additional plates riveted to the flanges, which would give a variable section of girder to which the formulæ contained in this Paper would not strictly apply; but in practice such exactness is rarely required, and usually the theories applicable to girders of constant section are extended to those whose section is variable.

It should be observed that there is no absolute contradiction of terms in the expressions "equal resistance" and "equal flexibility": ϵ being constant, or the moment of inertia constant, does not imply a constant section, the height only has to vary conformably. Suppose, for instance a double T section where the height a varies, the thickness e of the web being constant, the flanges having a constant breadth b, and a variable thickness z. The moment of inertia, $I = \frac{e\,a^3}{12} + \frac{b\,z\,a^2}{2}$ approximately, can remain constant as the variations of z can neutralise those of a, and therefore the resistance $\frac{2\,R\,I}{a}$ can vary according to an arbitrary law. Let it decrease uniformly to a third of its original value, M, from one end to the other of the swinging portion of the bridge, then $\frac{2\,R\,I}{a} = M\frac{3\,l - 2\,x}{3\,l}$, which makes a increase as the ordinate of the hyperbola $a = \frac{6\,R\,I\,l}{M\,(3\,l - 2\,x)}$, whilst in reality, owing to the progressive diminution of z, the area of the section, and therefore the weight, diminishes. It would, however, be most unadvisable, for the sake of reconciling theory with economy of materials, to erect such a structure, deceptive to the eye, and increasing in apparent size where in reality it decreases in strength. In spite of the theoretical advantages shown by the formulæ, the true principles of art require a diminution in height where the strength diminishes, unless a constant height is preferred.

The summary process of applying to girders of variable section formulæ established for a constant section is justified by the difficulties which would often attend more exact calculations, and the Author does not propose to undertake a revision of the general formulæ for the purpose of adapting them to the case of girders of equal resistance. The solution of the problem will be more easily obtained by investigating the special case of some large work. As a specimen of the principle, and the method of calculation, two simple instances will be investigated.

The first instance selected is when the bridge is strengthened near its central support, and it is proposed to investigate merely the special effect of the disturbance of the level, by wedging up, on a girder uniformly strengthened along a portion of its length. In fact it is proposed to resume the investigation of the effects of wedging on the hypothesis that the moment of inflexibility ϵ, instead of extending all along the length $l + l'$, has a higher value ϵ_1 on each side of the central support along the lengths λ, λ' (Fig. 9), in the spans l, l' respectively.

FIG. 9.



The reaction F at the support A is equal to $\frac{m}{l}$, since it must produce a bending moment $F\,l = m$ on the central support, and the equation of elasticity is $\epsilon_1 \frac{d^2 y}{dx^2} = m\frac{l-x}{l}$ to $x = \lambda$, and $\epsilon\frac{d^2 y}{dx^2} = m\frac{l-x}{l}$ from λ to l, and integrating, the equations become

$$\epsilon_1 y = \frac{m}{6\,l}(l-x)^3 + c\,x - \frac{m\,l^2}{6};$$

$$\epsilon y = \frac{m}{6\,l}(l-x)^3 - c\,\epsilon\,\frac{l-x}{\epsilon_1} - m\,\frac{\epsilon_1-\epsilon}{2\,\epsilon_1}(l-\lambda)^2\left(1-\frac{x}{l}\right) + \epsilon\,h.$$

Since y is the same for both curves where $x = \lambda$,

$$\frac{c}{\epsilon_1} = \frac{h}{l} + \frac{m}{3\,\epsilon_1}\left\{\frac{l}{2} - \frac{\epsilon_1-\epsilon}{l^2\,\epsilon}(l-\lambda)^3\right\};$$

and a similar relation exists for l' when $x = \lambda'$; and as the curves have a common tangent at the central support $c - \frac{m\,l}{2} = -c' + \frac{m\,l'}{2}$, and consequently

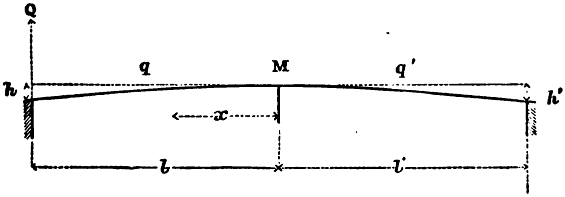
$$\frac{3\,\epsilon_1}{m}\left(\frac{h}{l} + \frac{h'}{l'}\right) = \frac{\epsilon_1-\epsilon}{\epsilon}\left\{\frac{(l-\lambda)^3}{l^2} + \frac{(l'-\lambda')^3}{l'^{\,2}}\right\} + l + l'.$$

If in this equation $\epsilon_1 = \epsilon$, $l = \lambda$, and $l' = \lambda'$, or λ and λ' are equal to zero, it will return to the form previously obtained for the more simple case.

The second instance to be investigated is where ϵ is proportional to $l - x$. This simple case, which would be likely to occur when a bridge rests upon the pivot, is where ϵ varies as the ordinates of a straight line and becomes zero at the extremity, and where the bridge would only be subjected to uniform loads over the whole span.

In the span l (Fig. 10), q being the load per unit of length, and

FIG. 10.



M the moment of the central support, the reaction, Q, at the extremity must satisfy the equation

$$-Ql+\frac{ql^2}{2}=M;$$

and therefore $$Q=\frac{ql}{2}-\frac{M}{l},$$

and the equation of elasticity is

$$\epsilon\frac{d^2y}{dx^2}=\frac{q}{2}\,(l-x)^2-Q\,(l-x)=(l-x)\left(\frac{M}{l}-\frac{qx}{2}\right);$$

and making $\epsilon=\frac{l-x}{k}$, where k is a constant, it becomes

$$\frac{d^2y}{dx^2}=k\left(\frac{M}{l}-\frac{qx}{2}\right),$$

and integrating, $$y=\frac{kx^2}{2}\left(\frac{M}{l}-\frac{qx}{6}\right)+cx;$$

and in order that this expression may become equal to h when $x=l$ it is necessary that

$$c=\frac{h}{l}-\frac{k}{2}\left(M-\frac{ql^2}{6}\right).$$

For the span l', with a co-efficient $k'=k\frac{l'}{l}$, and consequently $\epsilon=l\frac{l'-x'}{kl'}$, which restores the value $\frac{l}{k}$ at the pivot, an analogous equation is obtained, $c'=\frac{h'}{l'}-\frac{kl'}{2l}\left(M-\frac{q'l'^2}{6}\right)$; and as the tangential continuity of the two curves at the point of support gives $c = -c'$, the following relation is obtained, $M\ (l + l') = 2\,\frac{l\,h' + l'\,h}{k\,l'} + \frac{q\,l^3 + q'\,l'^3}{6}$. This equation gives the initial moment M, on which the values of all the other moments depend.

As a numerical illustration, assume the case of a bridge having two equal openings, l and $l' = 65 \cdot 6$ feet, carrying a railway, the dead load supported by one girder being 0·27 ton per lineal foot, and the rolling load 0·75 ton per lineal foot. The maximum moment when the bridge is open is $0 \cdot 27 \times \frac{(65 \cdot 6)^2}{2} = 580$. When the bridge is closed with its supports at the same level, and considering only the total loads for each span, the full load $q = q' = 0 \cdot 27$ ton $+ \ 0 \cdot 75$ ton $= 1 \cdot 02$ ton, so that $M = 1 \cdot 02 \times \frac{(65 \cdot 6)^2}{6} = 731$, and with only one span loaded $q = 1 \cdot 02$ ton, $q' = 0 \cdot 27$ ton, and $M = \frac{q + q'}{12}\, l^2 = 462$.

As the bridge is symmetrical, the diagram need only be drawn for one span (Plate 5, Fig. 12). The equations of the parabolas representing the moments are—

Both spans loaded,

$$\mu = 731 - 44 \cdot 6\, x + \cdot 51\, x^2.$$

Span represented in diagram alone loaded,

$$\mu = 462 - 40 \cdot 5\, x + \cdot 51\, x^2.$$

The other span alone loaded,

$$\mu = 462 - 15 \cdot 9\, x + \cdot 135\, x^2.$$

These curves give the following abscissæ of inflexion—

21·88 feet, 13·84 feet, and 52·26 feet respectively;

and the following maxima negative moments,

244 at the abscissa $x = 43 \cdot 73$ feet;
342 „ „ $x = 39 \cdot 73$ „
6 „ „ $x = 58 \cdot 92$ „

It is evident that in this case the curve for the open bridge does not rise so high at the central support as the curve for the closed bridge subjected to the full load, and it is only in the zone of the inflexions that it is higher than the others.

Having found the moments when the supports are at the same level, it remains to consider what advantage could be gained by further wedging up. As the girder is made of equal resistance throughout, it is the mean moment, namely, the surface B D K P Q, together with the surface Q R S A, that must be made a minimum by changing the position of the axis A B to A B′. Supposing the displacement of the axis to be infinitely small, and the curve A P K fixed, one portion of the area would decrease by B B′ O Q, and the other would increase by O Q A, and it would be advantageous to move the position of the axis either upwards or downwards till the increase and decrease become equal, or $\frac{BB' \times AB}{2} = QO \times AQ$, which condition is fulfilled when $AQ = \frac{1}{\sqrt{2}} AB$. Taking then the point Q′ satisfying this condition (A Q′ = 46·4 feet), and drawing the ordinate P′ R′ to the points P′ and R′ on the curves of the positive and negative moments, and bisecting it at O′, the straight line A O′ B′ is the axis which would afford the minima mean moments. This geometrical construction, however, applies merely to the curves of moments for the bridge when shut; but for the open bridge the change of axis would only raise the arc P′ K to F V, and the advantage of wedging could only be established by comparing experimentally the eliminated area Q′ B B′ O′ with the added areas A Q′ O′ + F V K P′. But allowing, for the sake of brevity, that B B′ represents the moment of the wedging force definitely chosen, by turning up on A B′ the limiting curves of the negative moments, the circumscribing envelope D V F G A of the absolute values of the limited moments is obtained.

The question naturally arises, how far theory is in accordance with facts. If the girder has a constant height, its moment of resistance will increase lineally as the moment of inertia, and to make it agree with the assumed hypothesis it could be fixed according to the straight line A D on the diagram; but in that case there would be an excess of strength along the half of the span nearest the centre, and a deficiency of strength along the other half. The tangent D G H, if substituted for D A as the line representing the moments of resistance, would remedy the deficiency, and might, moreover, be redrawn with considerable exactness by constructing for it a fresh diagram of moments intermediate between that drawn and that which would apply to the case of ϵ being constant, as the line D H is a mean between D A, conformable to the hypothesis $\epsilon = \frac{l - x}{k}$, and D I (parallel to A B′) when ϵ is constant.

It must be observed that, with this method of determining the section of the girder, the most advantageous wedging force will no longer be such as would produce a negative moment equal to B B′, as the trapezium A B′ D H must be made a minimum interval of the circumscribing envelope of the bending moments.

If the height of the girder varies, as is frequent in the case of large swing bridges, the lineal variation assumed for the moment of inertia I will cause a curved variation of the moment of resistance $\frac{2\,\mathrm{R}\,\mathrm{I}}{a}$, where R is the co-efficient of resistance for a unit of section, and a the height of the section. If, for example, with $\mathrm{I} = \frac{l - x}{k\,\mathrm{E}}$, where E is the modulus of elasticity, a varies according to the parabola $a = a' \frac{l^2 - x^2}{l^2}$, the moment of resistance will vary according to the hyperbola,

$$\frac{2\,\mathrm{R}\,\mathrm{I}}{a} = \frac{2\,\mathrm{R}}{a'\,k\,\mathrm{E}} \times \frac{l^2}{l + x},$$

where a' is the central height chosen.

For instance, let R = 8,534 lbs. per square inch in the central section, E = 25,600,000, $a' = 11 \cdot 15$ feet, then $\frac{2\,\mathrm{R}\,l}{a'\,k\,\mathrm{E}} = 731$, the maximum bending moment less the wedging-up force, whose moment, in order to make use of the same diagram, shall be assumed to be B B′; therefore $\frac{2\,\mathrm{R}\,l}{a'\,k\,\mathrm{E}} = \mathrm{D\,B'} = 613$; and therefore $k = \frac{1}{156{,}273}$, and the moment of resistance $\frac{2\,\mathrm{R}\,\mathrm{I}}{a} = \frac{40{,}213}{65 \cdot 6 + x}$. The curve D T U representing these moments of resistance is drawn on the diagram, with A B′ as the axis of x, which, besides being theoretically correct, might be adopted with advantage in practice.

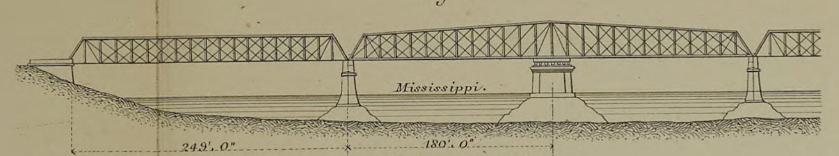
The force of wedging and the amount of lift to produce a central moment equal to B B′, on the hypothesis $\epsilon = \frac{l - x}{k}$, are readily obtained. The normal reaction is

$$\mathrm{Q} = \frac{q'\,l}{2} - \frac{\mathrm{M}}{l} = \frac{q'\,l}{3} = \frac{\overset{\text{Tons.}}{0 \cdot 27} \times 65 \cdot 6}{3} = 5 \cdot 9 \text{ tons},$$

to which must be added $\frac{\mathrm{B\,B'}}{l} = \frac{118}{65 \cdot 6} = 1 \cdot 8$ ton, so that the whole force is 7·7 tons; and both extremities are raised through a

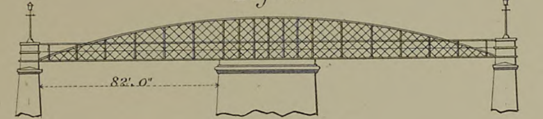
SWING BRIDGES.

Fig: 1.


Mississippi.
249'. 0"
180'. 0"

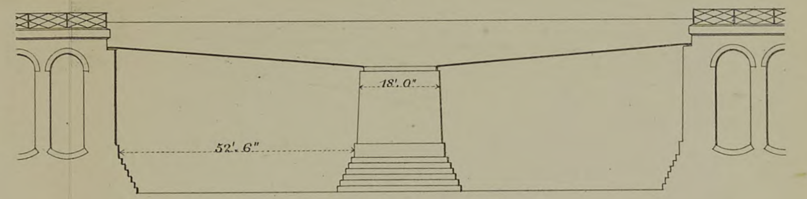
QUINCY BRIDGE.
Scale: $\frac{1}{2000}$.

Fig: 2.



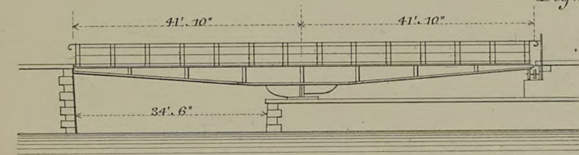
BRÊME BRIDGE.
Scale: $\frac{1}{1000}$.

Fig: 3.



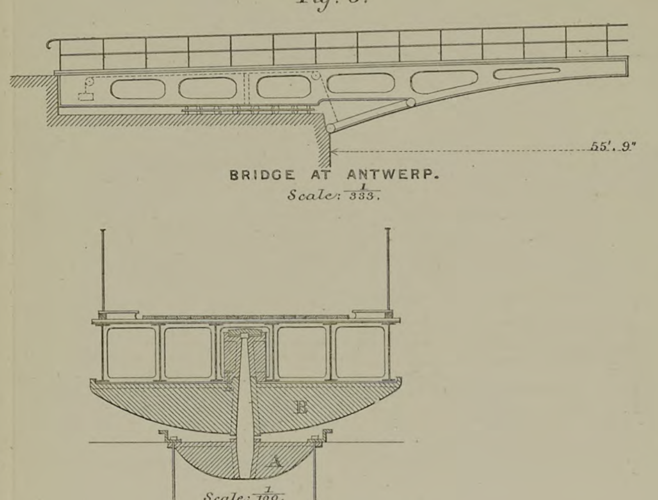
HOLLANDSCH-DIEP BRIDGE.
Scale: $\frac{1}{500}$.

Figs. 4.


41'. 10"
41'. 10"
34'. 6"

Scale: $\frac{1}{400}$. BRIDGE AT ROTTERDAM.

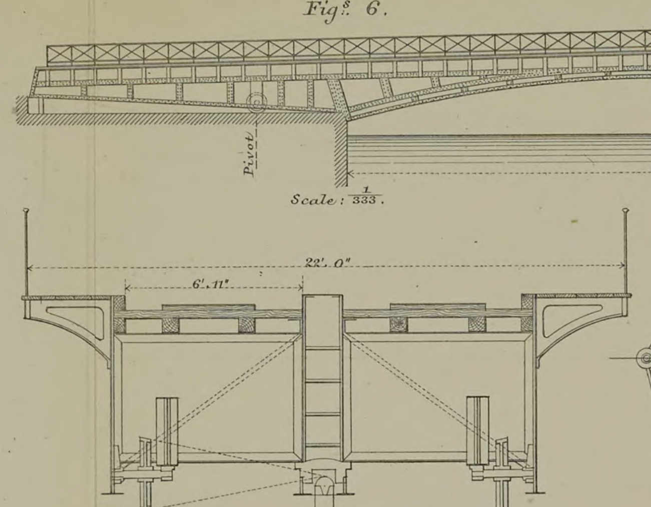
Fig: 5.



BRIDGE AT ANTWERP.
Scale: $\frac{1}{333}$.

Scale: $\frac{1}{100}$.

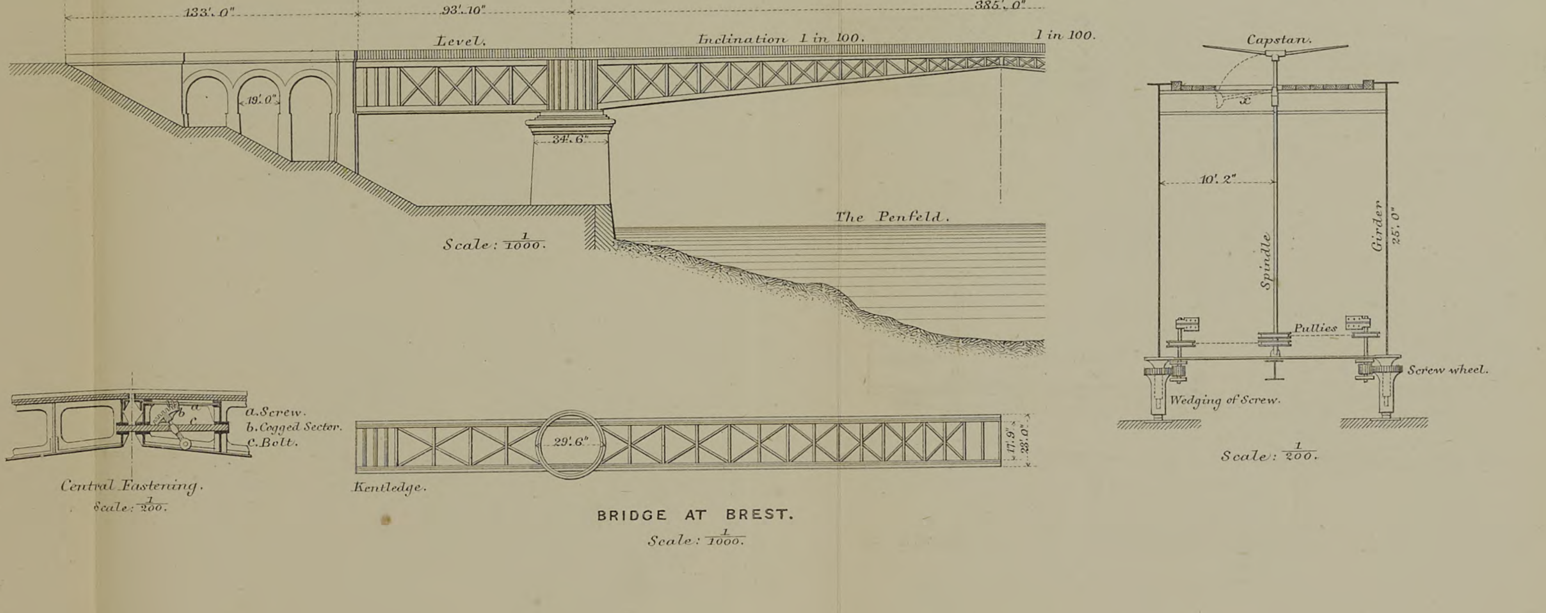
Figs. 6.


Pivot
Centre Line
100'. 0"
22'. 0"
6'. 11"

Scale: $\frac{1}{333}$.

BRIDGE AT HAVRE.
Scale: $\frac{1}{80}$.

Figs. 7.


133'. 0"
93'. 10"
385'. 0"
Level.
Inclination 1 in 100.
1 in 100.
19'. 0"
34'. 6"
The Penfeld.
Capstan.
x
10'. 2"
Spindle
Girder
25'. 0"
Pullies
Screw wheel.
Wedging of Screw.
a. Screw.
b. Cogged Sector.
c. Bolt.
Kentledge.
29'. 6"
17'. 9"
28'. 0"

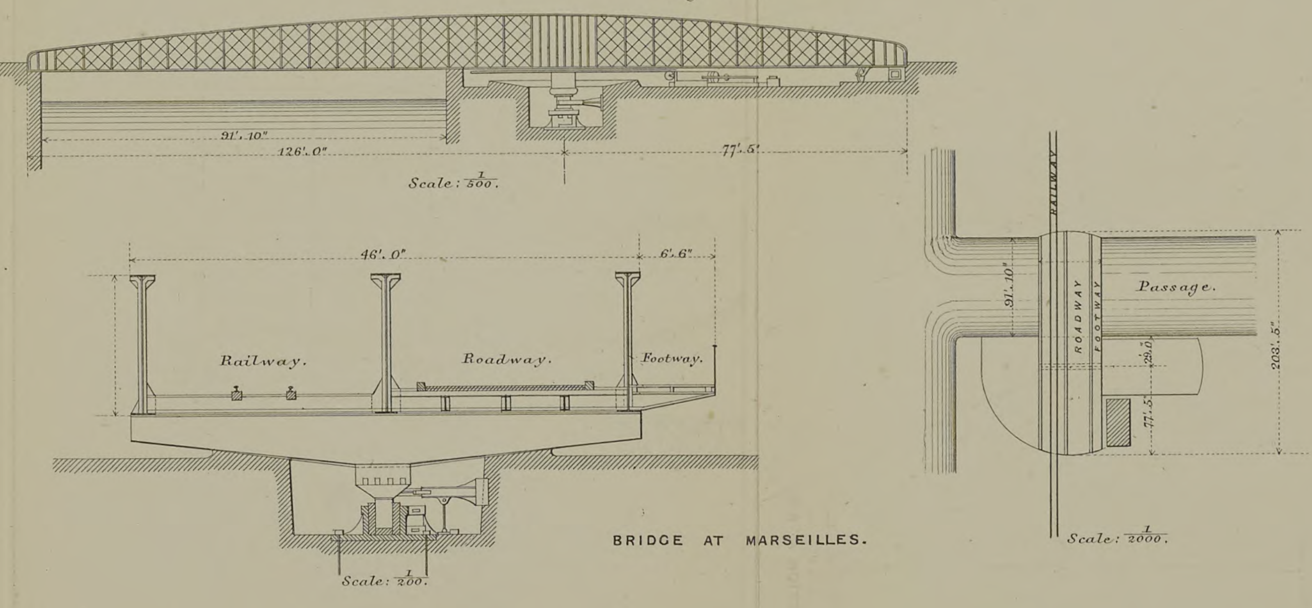
Scale: $\frac{1}{1000}$.

Scale: $\frac{1}{200}$.

Central Fastening.
Scale: $\frac{1}{200}$.

BRIDGE AT BREST.
Scale: $\frac{1}{1000}$.

Figs. 8.


91'. 10"
126'. 0"
77'. 5"
46'. 0"
6'. 6"
Railway.
Roadway.
Footway.
RAILWAY
ROADWAY
FOOTWAY
Passage.
91'. 10"
29'. 0"
77'. 5"
203'. 5"

Scale: $\frac{1}{500}$.

Scale: $\frac{1}{200}$.

BRIDGE AT MARSEILLES.

Scale: $\frac{1}{2000}$.

Fig: 9.

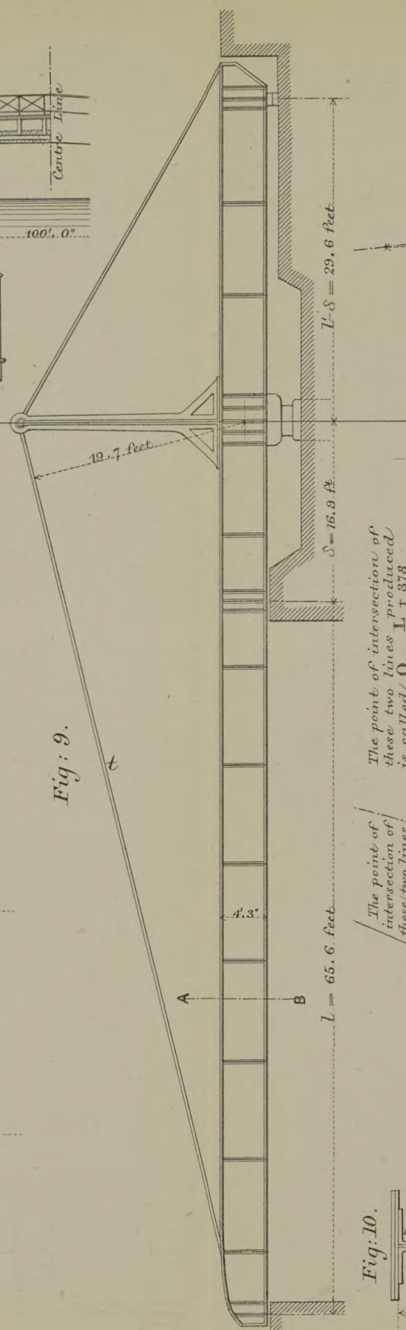
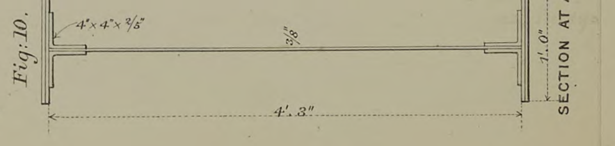
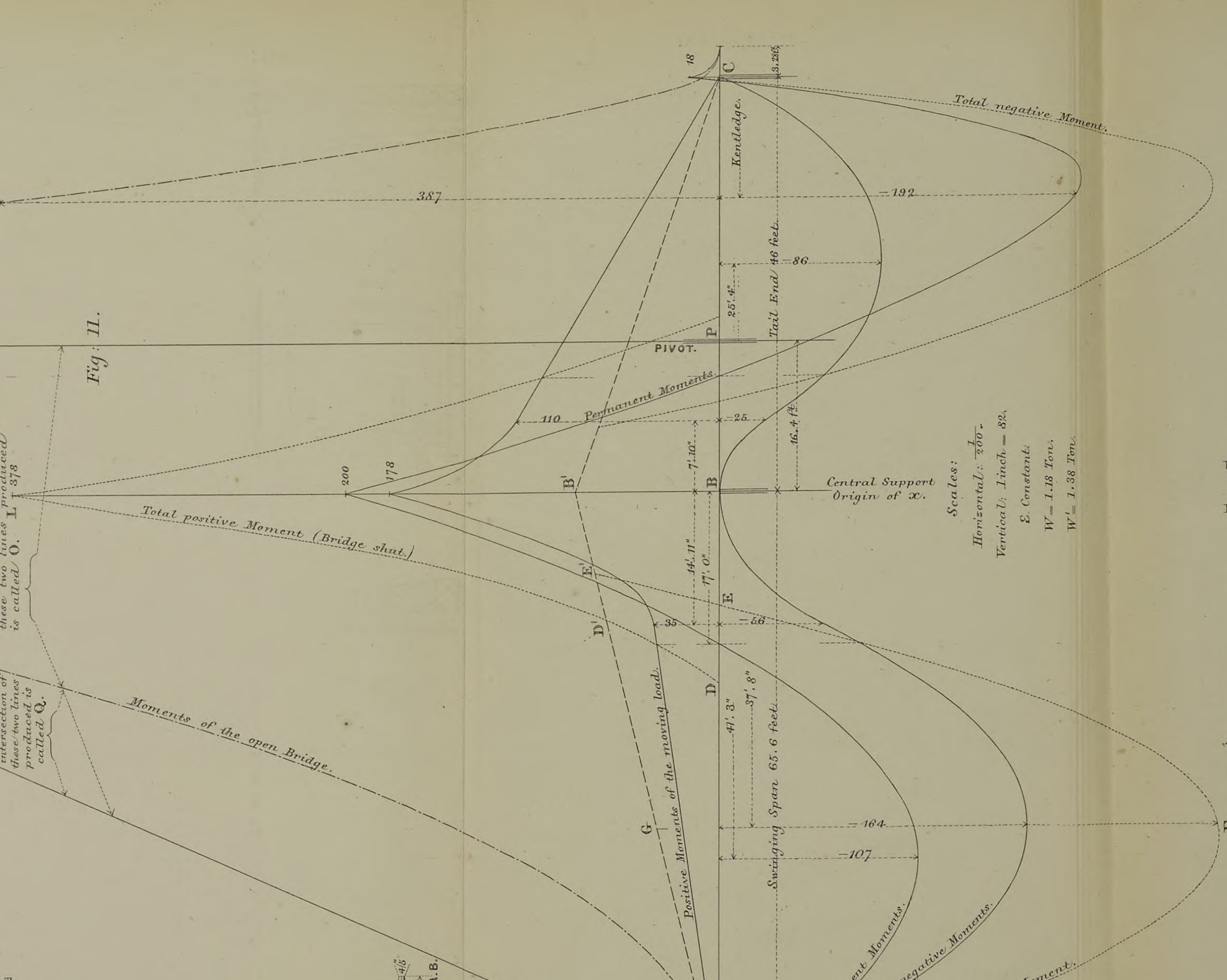

19.7 feet
t
4'. 3"
A
B
l' - δ = 29.6 feet
δ = 16.9 ft.
l = 65.6 feet

Fig: 10.


4" × 4" × 2/5"
3/8"
4'. 3"
1'. 0"
4 1/2"

SECTION AT A.B.

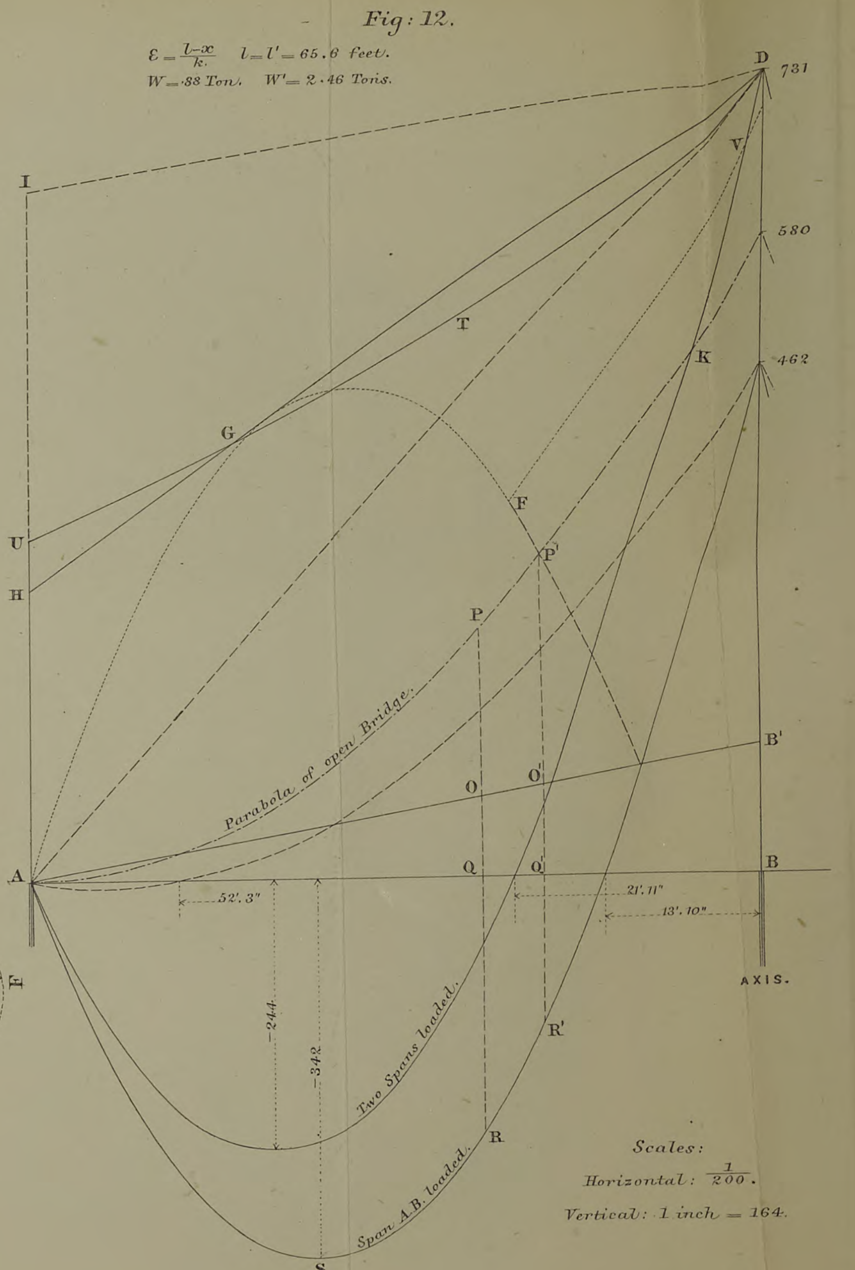
Fig: 11.



Scales:
Horizontal: $\frac{1}{200}$.
Vertical: 1 inch = 82.
ℰ Constant.
W = 1.18 Ton.
W' = 1.38 Ton.

Fig: 12.

$\mathcal{E} = \frac{l-x}{k}$. $l = l' = 65.6$ feet.
W = ·88 Ton. W' = 2·46 Tons.



Scales:
Horizontal: $\frac{1}{200}$.
Vertical: 1 inch = 164.

J. GAUDARD, DELT

THOS KELL, LITH. 40, KING ST COVENT GARDEN

height h either together or one after the other, which latter plan is the best, as then the first is raised with less expenditure of force. The height $h = \frac{k\,l\,m}{2} = \frac{65 \cdot 6 \times 118}{2 \times 156{,}273} = 0 \cdot 025$ foot; and the total amount of lift, including that for neutralising the deflection at the centre of the open bridge, is $\frac{7 \cdot 7}{1 \cdot 8} \times 0 \cdot 025$ foot $= 0 \cdot 106$ foot.

The accidental increase of pressure due to curvature caused by dilatation can be calculated in the same manner as the wedging force has been calculated. A case of this kind occurred at the bridge over the Missiessy dock at Toulon. The upper flange of the girder was heated by the sun's rays, whilst the lower flange was sheltered by the planking and by the web plate, causing a curving of the girder, and the pressure on the wedging apparatus was so great that the process of opening was made almost impossible, and the plates were considerably strained. The mischief was repaired by covering the top flange with wood, allowing free circulation for the air.

Diagrams form only part of the work in designing a structure, and detailed drawings must be made before the suitability of the proposed arrangements can be ascertained with certainty; but the general considerations the Author has brought forward show the possibility of investigating in most cases with sufficient accuracy what are the conditions of resistance of a swing bridge, even of variable section, and what are the most suitable arrangements to adopt.

The communication is accompanied by reduced drawings, from which Plate 5 has been engraved.

No. 1,485.—"The Testing of Portland Cement."

By Isaac John Mann.

In testing Portland cement it is usual to examine the colour, weight, pulverisation, and tensile strength. These properties are here enumerated in the inverse order of their importance, the three first being subservient to the last. It is hardly possible to compare accurately the results obtained by different investigators, as the experiments should be made under similar conditions as regards weight, fineness, and method of gauging, but hitherto this uniformity has not been observed.

Colour.

Good Portland cement, in its dry ungauged condition, is of a uniform dull grey colour; occasionally a slightly greenish hue is observable, sometimes replaced by a slight buff tint. A yellow or earthy colour is almost invariably indicative of inferior quality. The colour can be best observed by pressing a small quantity on a sheet of white paper with a clean smooth trowel, or a piece of sheet glass. But this test alone is insufficient as a guide, as inferior cement may possibly pass it, though good cement rarely, if ever, has the objectionable colour referred to.

Weight.

The recorded weight of cement, as at present obtained, depends very much on the manner of weighing. A method, frequently adopted, as giving the most uniform results, is as follows: dry cement, as received from the manufacturer, is allowed to flow from a small hopper-headed shoot into a counterpoised measure of known capacity—usually referred to the imperial bushel—any surplus in the measure being carefully struck off with a light straight-edge; it is then weighed. Instead of a shoot, a vessel shaped like a colander, with holes from ½ to ¾ inch in diameter, has also been used. The object in each case is to prevent compression. Weighed after this manner, Portland cement varies from 98 lbs. to 130 lbs. per bushel—equivalent to from 78 lbs. to 102 lbs. per cubic foot. It is difficult to conceive why such a measure of capacity as the bushel (which contains 8 gallons, equivalent to 1·283 cubic foot) should have been selected, as it is not easy of comparison with the usual standards of cubical measurements, the cubic foot being manifestly preferable in every respect.

The weight of cement, ascertained as described or in any analogous manner, bears a very uncertain ratio to its strength, as may be seen from Table 1, which gives the averages of a large number of experiments on cement from different London manufacturers.

TABLE 1.—RELATION BETWEEN the WEIGHT and TENSILE STRENGTH of CEMENT.

Age of Samples seven days; fineness from 6 per cent. to 10 per cent.; time occupied in setting thirty minutes to two hours.

Weight per cubic foot in lbs. . .	80	81	82	83	84	85	86	87[1]	88	89
Breaking weight per square inch in lbs. . . .	373	353	418	397	399	405	383	463	399	408

[1] Including some samples of cement of exceptionally high tensile strength.

For convenience of comparison the following tables have been extracted from the Papers submitted to the Institution by Mr. Grant and Mr. Colson.[1]

MR. GRANT'S SUMMARY of TESTS "SHOWING INCREASE of STRENGTH with INCREASED SPECIFIC GRAVITY."

Age of Samples seven days.

Weight per bushel in lbs. . .	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130
Breaking weight of 2·25 square inches in lbs. . .	473	592	650	647	708	694	687	702	700	705	768	718	644	778	732	706	717	674	820	816	657	865	917	920	914

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 104; and vol. xli., p. 125.

The fineness of the cement is not given, and it is apparently assumed that the weight of loose cement in air is an index of its specific gravity. The increase of strength is shown to be by no means uniform, for, to mention one instance only, cement weighing 110 lbs. per bushel exceeded in strength that weighing 126 lbs.

The results of Mr. Colson's numerous experiments on this subject have been epitomised thus:—

Age of Samples seven days.

Weight per bushel in lbs. .	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
Breaking weight of 2·25 square inches in lbs. .	747	688	719	708	729	675	745	706	718	702	732	676	631	545	603	558

The cement experimented on appears to have been heavier than that which the Author has had an opportunity of testing. The same deduction, however, is derivable from each of the tables, viz., that there is no fixed relation between the weight of cement, as at present ascertained, and its tensile strength.

In dealing with the question of weight, it is necessary to consider the methods of weighing. These are unsatisfactory and open to objections; the ascertained weights bear no definite relation to the real density, and depend, *cæteris paribus*, on the degree of pulverisation—finely-ground cement appearing to weigh less per cubic foot than the same cement when coarsely ground, so that, in many cases, difference of weight may simply mean difference in degree of pulverisation. With the same cement also the results are not always similar, even when weighed by one person two or three times in succession. Although there does not appear to be much, if any, connection between the weight of cement, as heretofore obtained, and its tensile strength, it would probably be erroneous to assume that the strength is unaffected by the actual density or specific gravity.

It is, therefore, suggested that the present unscientific and comparatively useless operation of weighing should be discarded, and the specific gravity be taken instead. That this has not hitherto been done is probably due to the trouble and difficulty experienced in obtaining the specific gravity by the ordinary method. In the case of Portland cement a liquid must be used which does not chemically affect it. The specific gravity of this liquid has also to be taken, and the results reduced to the standard of distilled water, involving tedious arithmetical calculations.

To obviate these difficulties, and to enable the operation to be performed with facility and expedition, the Author has devised an extremely simple gravimeter. It consists of a small glass vessel holding, when filled to a mark (A, Fig. 1) on the neck, a given quantity of liquid, and of a glass pipette furnished with a graduated stem and stop-cock, and containing, when filled to a mark (B, Fig. 2) on its upper extremity, a volume of liquid equal to that held by the first-mentioned vessel, *minus* the quantity displaced by 1,000 grains of the densest substance intended to be examined.

Fig. 2.

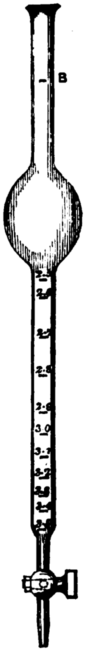
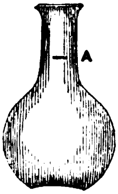


Fig.1.



Scale ¼.

In using the gravimeter the pipette is filled to the mark (B) with paraffin, turpentine, spirits of wine, or any other liquid which does not act on the cement, preferably paraffin; 1,000 grains of the cement are then introduced into the smaller vessel, which is placed under the pipette and filled to the mark A. Before this is quite completed the vessel may be corked, and the contents shaken to remove any small air-bubbles that may be entangled in the cement. The height of the column of liquid remaining in the pipette determines the specific gravity, which can be at once read off on the graduated stem. It is manifest that the denser the substance operated upon, the less liquid will be displaced in the smaller vessel, and therefore the less will remain in the pipette, and *vice versâ.* In reading the accompanying gravimeter, the second place of decimals is estimated. Any greater degree of delicacy may be obtained either by diminishing the diameter of the stem or by reducing the range.

The specific gravity of any solid substance coming within the range of the instrument can, of course, be taken in the same manner. The advantages claimed for this gravimeter are, that neither the density nor the temperature of the liquid used need be taken into account; one weighing is sufficient, and all arithmetical calculations are dispensed with; it is also inexpensive, and requires little skill in manipulation.

In order to test the accuracy of the instrument, a small piece of granite was reduced to powder and its specific gravity taken by the gravimeter; the specific gravity of an unpulverised piece was then ascertained by the ordinary method. Similar experiments were also made with a piece of limestone. The results were—

Granite	Specific gravity by gravimeter	2·62
	„ „ ordinary method	2·63
Limestone	Specific gravity by gravimeter	2·70
	„ „ ordinary method	2·71

Some of the results obtained in comparing the weight of cement of various manufacturers, as usually taken, with the actual density or specific gravity, are shown in Table 2.

TABLE 2.

Weight of 1 cubic foot of Cement, as ordinarily obtained.	Specific Gravity.
lbs.	
75·50	2·91
81·50	2·80
83·25	2·96
84·25	3·03
85·00	2·93
85·00	2·96
85·50	2·82
87·50	2·91
89·00	2·96

The weight therefore, as ordinarily found, bears no relation to the density. Taking the whole number of experiments (about fifty) the specific gravity varied from 2·77 to 3·03, the average being 2·91, showing that Portland cement is heavier than ordinary building stone. The specific gravity of a number of specimens of fine sifted cement gave an average of 2·9; that of the coarse particles of the same cements being 2·93. The density of a specimen of unground clinker was 2·55; the clinker contained numerous small air-holes, which accounts for the specific gravity being less than that of the ground cement. Some samples of gauged cement, the age of which was three months, had an average density of 2·21, the extremes being 2·07 and 2·45.

PULVERISATION.

The degree of pulverisation at present demanded in this country seems to depend upon the judgment of the Engineer. In the Author's experiments, the fineness of the cement was measured by a sieve with circular perforations, the perforations being 0·0231 inch in diameter. Coarsely-ground cement, when gauged neat, generally possesses greater tensile strength than finely-ground cement. On this subject a series of experiments was made by the Author, some of the results of which are given in Table 3.

The "fine sifted" cement was that which passed through a sieve with apertures 0·0231 inch in diameter, the various degrees of coarseness being produced by adding the requisite amount of coarse particles, care being taken to mix them thoroughly with the fine. Each number represents the average breaking weight per square inch of from three to six samples; the age of the samples was seven days, and they were taken promiscuously from the cement of different London manufacturers, and of one French manufacturer.

The experiments of Mr. Colson on this subject[1] confirm those of the Author, for with samples one month old, the breaking weight of 2¼ square inches was, for fine screened cement, 939 lbs., and for coarse unscreened, 989 lbs. When the age of the samples was six months, the results were similar.

It appears singular that when the coarse particles are mixed with the fine particles the strength of the sample should be increased, as when gauged by themselves the coarse particles do not evince the slightest tendency to bond together or set, but remain loose and inert like so much sand. This result, however,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli.

TABLE 3.—EFFECT of COARSENESS on the STRENGTH of CEMENT. SAMPLES GAUGED NEAT.

Breaking Strain per square inch after seven days' immersion.

Fine sifted Cement.	Percentage of Coarse Particles.				
	5	10	15	20	25
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
355	..	435	..	..	..
439	..	..	..	..	471
476	441	493	477	..	..
313	288	324	323	..	357
403	..	466	406	369	404
471	..	505	..	..	..
333	331	369	412	..	..
443	458	465	..	..	..
396	..	400	..	..	..
392	..	392	386	..	..
257	..	..	..	286	..
445	430	..	437	..	..
..	410	445	458	..	..
371	..	319	435	453	..
394	402	404	429	426	..
486	..	558	560	541	..
462	449	463	463	467	..
183[1]	212	246	276	270	..
281	259	248	311	254	..

[1] Very slow-setting.

would seem to be in accordance with what occurs in the case of limes. Admitting Rondelet's statement, as to the adhesion of mortar to stone exceeding its own tensile strength,[1] to be true also of cement, then as the tensile strength of the unground particle *per se* may be assumed to exceed that of fine cement recently gauged, it follows that within certain limits the presence of the coarse particles, which may be conceived to act as minute stones, increases the strength of the aggregate above that of its matrix.

In the analogous case of hydraulic limes, the strength is similarly increased by the admixture of clean sand. The coarse particles of cement, although probably acting somewhat in the same way as the sand, seem to present additional facilities for the adherence of the fine cement to them. This may be seen from the following experiments, in which the cement of four different manufacturers was used, and a series of samples made from each; the grains of sand were somewhat larger than the coarse particles of the cement. The number of experiments is limited, but the results are marked.

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[1] *Vide* "Résumé des Leçons données à l'Ecole des Ponts et Chaussées." partie. Par M. Navier. 2e éd. Paris. 8vo, 1833, p. 15.

TABLE 4.—EFFECT of COARSE PARTICLES of CEMENT as COMPARED with SAND.

Fine sifted Cement and Sand in equal parts by Weight.			Fine sifted Cement and coarse particles in equal parts by Weight.		
Area	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.
Sq. inches.	lbs.	lbs.	Sq. inches.	lbs.	lbs.
2·26	472	209	2·27	510	224
2·25	452	200	2·26	402	178
2·25	360	160	2·24	517	230
2·28	530	232	2·27	850	374
2·32	522	225	2·30	965	419
2·32	567	244	2·34	945	404
2·32	400	172	2·27	662	291
2·32	422	182	2·36	622	263
2·30	422	183	2·25	600	266
2·22	580	261	2·28	963	422
2·25	592	263	2·30	937	407
2·25	610	271	2·28	1,060	465
Average . .		217	Average . .		328

The Author has frequently found, in the case of cement containing not more than 10 per cent. of coarse particles, that they may be replaced by sand without affecting the strength of the aggregate; beyond 10 per cent. the results were increasingly in favour of the coarse particles as compared with sand. In some instances, increasing the quantity of coarse cement from 10 to 100 per cent. only diminished the strength by about 12 per cent.

In order to ascertain the effect of coarsely-ground cement on mortar, experiments were made with cement, of various degrees of coarseness, and sand gauged in equal volumes; the mean results are given in Table 5. As before, the cement of different manufacturers was used, and each of the breaking weights given is the average of not less than three careful tests. From this table it would appear that, when diluted with an equal volume of sand, coarse cement does not give quite such favourable results as fine. From various considerations it seems probable that, in the proportion of 1 part of cement to 1 of sand, the limit is reached, if not exceeded, in which the coarse cement is as effective as the fine, and that beyond this limit the coarse particles act nearly the same as so much additional sand.

Table 5.—Effect of Coarseness on the Strength of Cement.

Samples gauged with Cement and Sand in equal volumes. Breaking strain after seven days' immersion per square inch.

Fine sifted + Sand.	Percentage of coarse Cement.		
	10 + Sand.	15 + Sand.	20 + Sand.
lbs.	lbs.	lbs.	lbs.
208	224	..	..
291	..	235	..
268	277	248	..
272	249	..	229
170	203	..	199
233	251	230	..
272	230	274	294
210	206	205	208
233	215	187	..
220	230	252	265
257	251	275	295
61[1]	150	98	103
175	187	179	176

[1] Twenty-four hours in setting.

In many instances the Author has found that mortar consisting of 1 part of cement to 3 parts of sand,—the cement containing 25 per cent. of coarse particles,—possessed little more than one-half the tensile strength of mortar gauged in the same proportions with fine sifted cement, the age of the samples being four weeks.

Mr. Colson's experiments lead to the same conclusion, and show that, gauged in the proportion of 1 of cement to 1 of sand, there was only a slight difference in favour of the fine cement; but that when gauged in the proportion of 1 of cement to 2 of sand, the coarseness of the cement had the effect of diminishing the strength to the extent of about 14 per cent. There can be no doubt that the diminution in the efficacy of the coarse cement will be more apparent as the proportion of sand is increased.

In the investigation of this part of the subject, which may be termed the mechanical agency of the cement particles, it is of the highest importance to understand, if possible, by what means the cementing material binds substances together. The explanation given by the French chemist Macquer, of the analogous action of limes,[1] is probably equally applicable to Portland cement. This is to the effect that the extreme fineness of the particles of lime which reduces it altogether to surfaces, gives it the faculty of adhering firmly to the surface of the sand, or stone, and with a force proportioned to the closeness of the contact. This explanation omits the effect produced by crystallisation, which probably acts an important part, the setting of cement being attributable to the formation of hydrated silicates and aluminates, such crystals adhering strongly to foreign substances; and as the more minute the division of the particles, the more perfect will be the subsequent crystallisation, an additional argument is presented in favour of finely-ground cement.

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[1] *Vide* Vicat "On Cements." Translated by Smith. London. 8vo, 1837, p. 126.

The extra cost of grinding cement, to the almost impalpable powder which theory would indicate, can hardly be compensated by the increased efficacy thereby obtained; but it is extremely desirable, and comparatively easy, to discover the limit at which extra grinding ceases to be economical. On the whole, the Author believes that cement, of which not more than 10 per cent. is stopped by a sieve with perforations $\frac{1}{50}$ inch in diameter, probably approaches the present economical limit.

In connection with the subject of mechanical agency, the Author has made some experiments on the effect produced by sands, of different degrees of granulation, on the strength of cement mortar. Some of the final results, as representing the average of a rather disconnected and tentative series of tests, are given in Table 6. In each case similar sand and cement were used, the various degrees of fineness being obtained by repeated sifting.

DETAILS of SIEVES.

		Inch	
No. 1	circular perforations	0·14	in diameter.
„ 2	„ „	0·10	„
„ 3	„ „	0·07	„
„ 4	„ „	0·02	„
„ 5	wire gauze	2,900	meshes to a square inch.
„ 6	„	8,200	„ „

The sand passing through No. 1 and rejected by No. 2 was considerably coarser than ordinary building sand. That passing No. 5 and stopped by No. 6 was of a degree of fineness frequently met with in practice, and known as 'woolly' or 'running' sand.

TENSILE STRENGTH.

As before observed, the tensile strength is the test to which all the others must be subservient. In practice cement has to resist both tension and compression; but its power to resist the latter is so closely allied to the resistance it offers to the former, as to render the test of tensile strength sufficient. In fact, it would appear that this test alone, if properly applied, not only to the cement in

Table 6.—Effect produced by Fineness of Sand on Strength of Mortar, 2 parts Sand to 1 part Cement by measure.

Age of Samples four weeks.

Sieves Nos. 1 and 2. Sand passing No. 1 but stopped by No. 2.			Sieves Nos. 2 and 3. Sand passing No. 2 but stopped by No. 3.			Sieves Nos. 3 and 4. Sand passing No. 3 but stopped by No. 4.			Sieves Nos. 4 and 5. Sand passing No. 4 but stopped by No. 5.			Sieves Nos. 5 and 6. Sand passing No. 5 but stopped by No. 6.		
Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.
Sq. ins.	lbs.	lbs.	Sq. ins.	lbs.	lbs.	Sq. ins.	lbs.	lbs.	Sq. ins.	lbs.	lbs.	Sq. ins.	lbs.	lbs.
2·22	375	169	2·20	292	133	2·34	279	119	2·26	200	88	2·22	198	89
2·22	375	169	2·30	295	129	2·30	270	117	2·22	230	103	2·21	170	77
2·18	375	172	2·32	285	122	2·40	292	121	2·21	220	99	2·21	185	83
2·18	375	172	2·32	287	123	2·25	270	120	2·24	240	107	2·23	210	94
2·22	398	179	2·22	278	125	2·22	284	128	2·24	245	109	2·24	103	46
2·22	396	178	2·22	295	133	..	..	..	2·25	270	120	2·21	135	61
2·25	406	180	..	..	..	..	..	..	..	..	..	2·20	219	99
2·17	456	210	..	..	..	..	..	..	..	..	..	2·25	210	93
2·17	452	208	..	..	..	..	..	..	..	..	..	2·17	208	95
2·23	442	198	..	..	..	..	..	..	..	..	..	2·26	214	94
2·17	363	167	..	..	..	..	..	..	..	..	..	2·20	216	98
2·17	418	192	..	..	..	..	..	..	..	..	..	2·26	216	95
Average .		183	Average .		127	Average .		121	Average .		104	Average .		85

its neat condition, but also when diluted with sand, would answer all practical purposes. It is proposed, therefore, to treat this part of the subject in detail, though it may unavoidably lead to some repetition of what is already known.

Method of Making the Sample Briquette.

This determines to a great extent the breaking weight. Everything that conduces to uniformity should be observed, and the mould should be carefully filled with gauged cement, so as to leave no air-holes or other defects.

The following method, adopted by the Author, gave good results[1]:—after being thoroughly mixed and incorporated by a light (plasterer's) trowel, the cement was packed closely into the mould, heaped a little higher than the edges, and pressure applied by means of a small board held in the hands of the operator; this may be done a second time, after adding a little dryly gauged cement. The pressure forces out any superfluous water, replaces it with cement, and prevents the occurrence of air-holes or other defects.

The application of pressure in the formation of the sample is not inconsistent, for in practice the cement, forming the joints of masonry or the matrix in concrete, is subject to much greater pressure by the weight of the superincumbent work. From a large number of experiments the Author found that the slight pressure referred to increased the strength of the sample more than 25 per cent. This result is satisfactory, as it shows that the pressure unavoidable in practice is probably beneficial. It is desirable to adopt every means to obtain the best results, and to develop as much as possible the strength of the cement under test. Manufacturers are liable to suffer some injustice from the want of proper care and skill in the making of test blocks, for two sets of samples of the same cement, presenting the same external appearance, can be made to give very different results, the strength of one being nearly double that of the other at the end of seven days.

Proportion of Water used in Gauging.

The least possible quantity of water should be used in gauging, any excess having a direct tendency to reduce the strength of the sample. For this reason Portland cement should not be tested while too fresh. If warm, it should be spread out and allowed to cool for a few days, and then be made into test blocks. The cooling process—by which the particles of lime are slowly slaked by the absorption of water from the air—has frequently produced an improvement in the strength of seven-day samples of about 40 per cent.

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[1] Except in the case of very slow-setting cement, only so much was gauged at a time as sufficed to make one sample, the water for gauging being added at one operation.

The following table gives some of the results obtained by using various proportions of water :—

TABLE 7.—CEMENT GAUGED with VARIOUS PROPORTIONS of WATER.

Age of Samples seven days. Average breaking weight per square inch.

	5 oz. Water to 32 oz. Cement.	6 oz. Water to 32 oz. Cement.	7 oz. Water to 32 oz. Cement.	8 oz. Water to 32 oz. Cement.	9 oz. Water to 32 oz. Cement.	10 oz. Water to 32 oz. Cement.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
	433	460	..	306	..	..
	416	435	..	296	..	..
	416	480	..	282	..	..
	344	398	382	363	223	184
	368	366	387	357	219	221
	329	416	353	339	211	197
	487	489	323	316	187	163
	474	447	420	302	234	165
	440	471	336	268	209	162
Averages . .	412	440	367	314	214	182

With 5 oz. of water to 32 oz. of cement the gauged cement was extremely dry, crumbling under the trowel, and could not be made to take a smooth surface; with the proportion of 6 oz. to 32 oz. it was moderately dry, and could be finished and smoothed off with the trowel; with 7 oz. to 32 oz. the mass was moderately wet; with 8 oz. to 32 oz. the samples were wet and soft; with 9 oz. to 32 oz. they had the consistency of stiff grout; and with 10 oz. to 32 oz. a liquid was produced which could be poured from one vessel to another. In the last two cases the samples shrank considerably, and must have lost some of the water by evaporation.

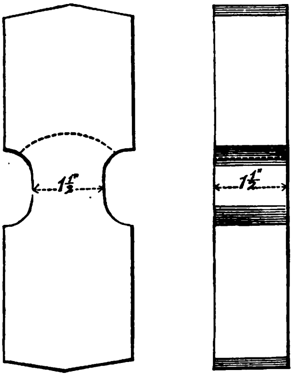
The time occupied in setting increased, in proportion to the quantity of water used, from fifteen minutes to about forty-eight hours. The effect of using an excessive quantity of water is manifest in seven-day samples, but it has been questioned whether the deterioration is permanent. Mr. Colson's experiments go to prove that the deterioration continues, the decrease of strength being more apparent in samples six months old than in others only seven days old. The best test blocks were made with from

6 oz. to 7 oz. of water to 32 oz. of cement; with this proportion the gauged mass presented a somewhat dry and granular appearance, but when placed in the mould and subjected to the small pressure before referred to, a little water exuded from under the mould, and the upper surface became soft and capable of being neatly smoothed off with the trowel.

SHAPE OF THE SAMPLE BRIQUETTE.

The form usually adopted (Fig. 3) appears capable of improvement. In the large majority of cases the line of fracture is not at the point of minimum section, but generally somewhat as shown by the dotted line in the left-hand figure. This result has been attributed to a peculiar effect produced by change of form on the strength of materials. The Author, however, believes it to be chiefly due to irregular strains produced by the clips holding the sample, which clips, having a tendency to collapse, lead to crushing strains. That some irregular strain of this kind takes place seems probable from the fact, that weak samples ordinarily break at the point of minimum section, while samples of greater strength, requiring the application of heavy strains, generally break through the thicker portion, the latter result apparently arising when the strain on the clips is sufficient to cause collapse. Differences also frequently occur in the breaking weights of samples of similar make and from the same cement.

FIG. 3.

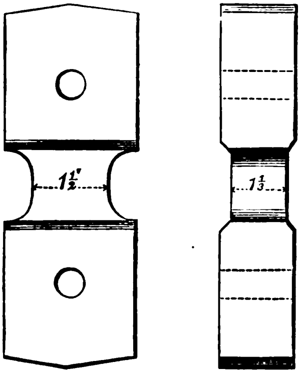


Scale ¼.

In order to avoid the use of clips, the Author had holes drilled in the samples and the narrow part reduced in area (Fig. 4); this reduction was made with a view to prevent fracture through the eye; they were then broken by steel pins passing through the eyes.

In this way an increase in the breaking weight of more than 12 per cent. was obtained, the samples in every case but one breaking through the smallest section.

FIG. 4.



Scale ¼.

Some of these experiments are given in Table 8. The samples on each horizontal line were made of the same cement, at the same time, and were gauged with a similar quantity of water.

TABLE 8.—COMPARISON BETWEEN ORDINARY SHAPED SAMPLES BROKEN with CLIPS and BROKEN with STEEL PINS PASSED THROUGH DRILLED HOLES.

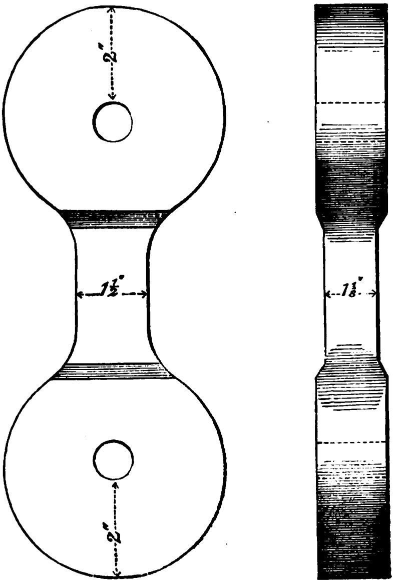
Age seven days.

Ordinary Shape. Broken with Clips.			Ordinary Shape. Broken with Steel Pins through Drilled Eyes.		
Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.
Sq. ins.	lbs.	lbs.	Sq. in.	lbs.	lbs.
2·32	790	340	1·800	830	461
2·32	875	377	1·650	755	457
2·36	845	368	1·800	663	368
2·32	884	380	1·830	832	454
2·34	951	406	1·830	834	455
2·30	967	420	1·800	773	429
2·30	910	395	1·545	695	449
2·32	910	385	1·635	800	489
2·36	999	423	1·635	825	504
2·25	999	444	1·570	776	494
2·32	1,087	468	1·680	924	550
2·30	1,026	446	1·650	645	391[1]
2·34	1,030	440	1·650	773	468
Average . .		407	Average . .		458

[1] Badly drilled.

Subsequently samples were made of the shape shown in Fig. 5, with which very satisfactory results were obtained; and it is believed that this, or some similar, shape will be found superior to the form now generally in use.

FIG. 5.



Scale ½.

In Table 9 some of the results of experiments made with the new-shaped sample are given. This table shows an increase of nearly 20 per cent. in favour of the proposed shape. In a few instances the samples broke through the eye, but this is attributable to the temporary character of the change in the testing-machine to adapt it to the altered samples, great care and accuracy being necessary, in order that the strain shall pass directly through the axis of the sample. The form suggested is similar to that generally used in testing the tensile strength of iron, and there does not appear to be any reason why what has been found most suitable for iron should not also apply to Portland cement. In this case also the samples on each horizontal line were under like conditions as to the cement, time, and quantity of water.

TABLE 9.—COMPARISON BETWEEN SAMPLES of ORDINARY SHAPE BROKEN with CLIPS, and of an IMPROVED SHAPE BROKEN with STEEL PINS PASSED THROUGH EYES MOULDED in the CIRCULAR ENDS of the SAMPLE.

Age seven days.

Broken with Clips. Ordinary Shape.			Broken with Steel Pins. Improved Shape.		
Area.	Breaking Weight.	Breaking Weight per Square Inch.	Area.	Breaking Weight.	Breaking Weight per Square Inch.
Sq. ins.	lbs.	lbs.	Sq. ins.	lbs.	lbs.
2·27	840	370	2·36	830	351
2·36	790	335	2·36	997	422
2·34	750	320	2·37	820	346
2·24	520	232	1·77	460	261
2·27	645	283	2·30	915	398[1]
2·40	880	366	2·45	1,120	457[1]
2·30	655	284	2·36	890	377[1]
2·25	637	283	2·34	790	337
2·23	590	264	2·28	712	312
2·26	545	241	2·32	717	309
Average . .		297	Average . .		357

[1] Broke through eye.

AGE AT WHICH THE SAMPLE BRIQUETTE SHOULD BE BROKEN.

The Author has confined his observations almost exclusively to seven-day samples, as that period seems to be universally adopted; but it may be questioned whether this age gives a fair test in all cases. If the cement is moderately quick-setting, becoming sufficiently hard to be removed from the moulds in from half an hour to five hours after gauging, the seven-day test is probably a fair exponent of the quality; with such cement, taking the average of several hundred experiments, the breaking weight of the cement at seven days was nearly always in direct relation to the breaking weight at twenty-eight days. Warm cement can be cooled by exposure, until the time of setting comes within the limits mentioned. In the case, however, of very slow-setting cement, requiring from six to twenty-four hours to harden, the breaking weight at seven days does not seem to bear the same ratio to the ultimate strength as in the quicker setting cement, the latter gaining strength more rapidly, although it may ultimately be inferior to that of the former.

The longer the time between the gauging and breaking of the samples, the more reliable are the results; but whether the advantage thus gained is a compensation for the inconvenience arising from the lengthening of the time seems doubtful. Generally, the cement, as received from the manufacturer, sets with sufficient quickness to enable its quality to be determined by the seven-day test. The difference in the strength of seven and twenty-eight day samples was found, from numerous experiments, to be about 20 per cent.

It might be desirable to introduce along with the ordinary seven-day test one including a longer period, say twelve weeks, so that if the first should appear unsatisfactory, which might occur in the case of very slow-setting cement, the latter could be tried before the cement was finally rejected.

It has been suggested that cement mortar should be made the subject of test, as it is in this form that Portland cement is usually employed in practice. If, however, the properties of cement are understood, and its behaviour when diluted with sand, &c., a test of this description is unnecessary.

Standard of Tensile Strength.

The standard test, specified at the commencement of the London Main Drainage works, was a breaking weight of 400 lbs. on an area of 2·25 square inches (equal to about 178 lbs. per square inch) after seven days' immersion. At present a tensile strength of 350 lbs. per square inch is frequently demanded and obtained, and it seems probable that the standard may be raised still higher, as the manufacture of the article improves and its properties become better understood.

In the Author's experiments, in which the moulds and testing-machine were those in ordinary use, it was not uncommon to obtain a strength of from 400 lbs. to 500 lbs. per square inch after seven days' immersion, and in one or two instances it rose as high as 600 lbs. per square inch. The average of a large number of tests made within the last two or three years has been 380 lbs. after seven days, and 450 lbs. per square inch for twenty-eight-day samples. The fineness of the cement was such that about 7 per cent. by weight was stopped by a sieve the perforations in which were about $\frac{1}{43}$ inch in diameter. Having due regard to the effect of fine grinding on the strength of neat cement, and to the rates at which the strength of different samples increases in the early periods of their age, the Author believes that a minimum breaking weight of from 350 to 370 lbs. per square inch is as much as can be reasonably expected from seven-day samples.

In conclusion, the Author would observe that the experiments he has been enabled to record are but limited, considering the nature of the subject dealt with. They were however made with great care, under his own direct supervision, most of them being spread over the last three or four years.

The Paper is accompanied by several diagrams, from which the woodcuts have been compiled.

CENTRIFUGAL PUMPS.

PLATE 6.

Fig: 1.

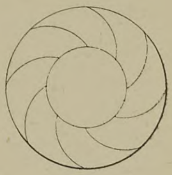


Fig: 2.

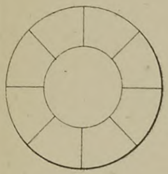


Fig: 3.

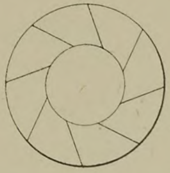


Fig: 8.

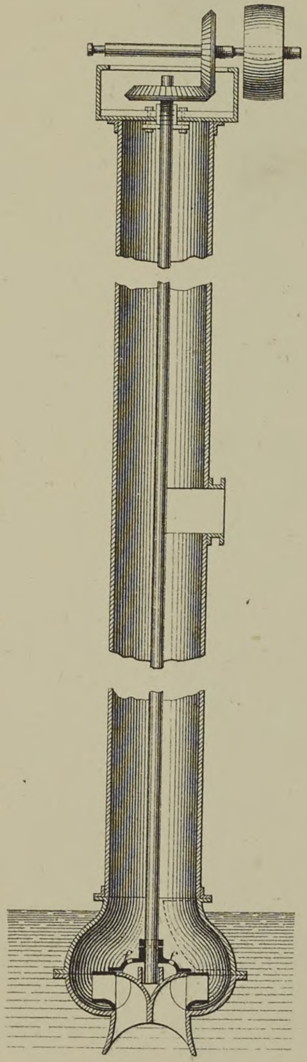


Fig 4.

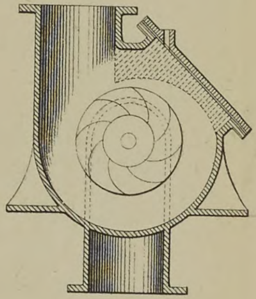


Fig: 5.

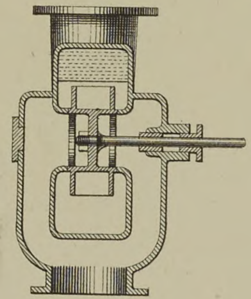


Fig: 6.

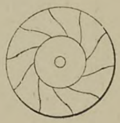


Fig: 7.

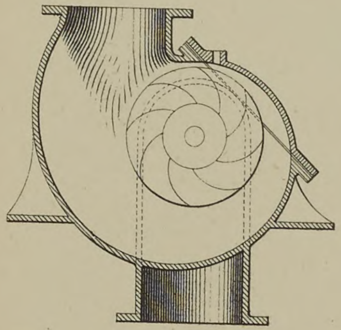


Fig: 9.

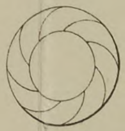
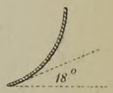


Fig: 10.



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RD CLERE PARSONS, DELT.

Minutes of Proceedings of The Institution of Civil Engineers. Vol. XLVII. Session 1876–77. Part 1.

THOS KELL, LITH.

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No. 63 *—"The Theory of Centrifugal Pumps, as supported by Experiment."[1] By the Hon. R. CLERE PARSONS, B.A., B.C.E. Dublin, Stud. Inst. C.E.

CENTRIFUGAL pumps are by no means a modern invention; the crude idea of which probably dates as far back as the middle of the last century, when the mathematician Euler brought out a primitive form of centrifugal pump, an account of which he published in the Proceedings of the Academy of Berlin for 1754. This pump is referred to by M. Combes,[2] the eminent French engineer, and also its theory, as deduced by Euler; but, as it has never come into practical use, it has probably failed, like most of the mechanical inventions of that great mathematician. From that period many rotatory and centrifugal pumps were invented, principally by French engineers, but none of them seems to have yielded even a reasonably good efficiency. The first mention[3] of a centrifugal pump at all to be compared with those of the present day is in the year 1830, when one was erected by Mr. McCarty in the Naval Yard at New York, and some improvements upon this machine were patented by him in the following year. No experiments upon this pump seem to have been published, consequently it is uncertain whether it yielded a good efficiency. The next epoch in the history[4] of the centrifugal pump is the Exhibition of the year 1851, when the late Mr. Appold achieved the great success with his pump of trebling the efficiency obtained by any other exhibitor. Mr. Appold, by making numerous experiments, at length determined that the efficiency mainly depended upon the form of the blades in the fan, and, further, that the best form was a curved blade pointing in the opposite direction to that in which the fan revolved (Plate 6, Fig. 1). Two other forms of fan which he tried were, one with straight radial blades, and another with straight blades inclined at an angle of 45° to the circumference (Plate 6,

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[1] This communication was read and discussed at a meeting of the Students on the 11th of February, 1876, and was awarded the Miller Scholarship in the Session 1875–76. Mr. Parsons was subsequently elected an Associate of the Institution.

[2] "Recherches théorétiques et expérimentales sur les roues à réaction ou à tuyaux."

[3] "Report of Juries of International Exhibition of 1851."

[4] *Ibid.*

Figs. 2, 3). Both these fans yielded efficiencies far inferior to the one with curved blades.

Another detail which affects the efficiency, but not to the same extent as the form of the blades of the fan, is the form of the casing surrounding the fan. The old theory which Morin, Appold, and many others held, and which is still advocated in some recent books, viz., that as long as the casing outside the fan is large enough it is immaterial of what shape it is, can be proved to be false both by theory and experiment. In January 1875 Mr. Anderson, M. Inst. C.E., of the firm of Messrs. Eastons and Anderson, deputed the Author, in company with Mr. Hesketh, Stud. Inst. C.E., to make some experiments upon centrifugal pumps, both with a view to determine the laws which regulate their discharge, and at the same time, if possible, to improve their efficiency. The first experiments were made upon a pump whose suction and discharge pipes were 10 inches in diameter. The fan was 14 inches in diameter, and the casing surrounding the fan was circular, as is shown in Plate 6, Figs. 4, 5.

This pump was driven by a single-acting engine working directly on to the shaft of the pump. The water was raised by the pump from a large cast-iron tank, and discharged back into it through a measuring tank. In the bottom of the measuring tank was a hole in a thin sheet-iron plate, and by the head of water maintained over this hole the discharge was calculated by the formula

$$Q = 0 \cdot 62 \times A \times \sqrt{2 g h} \text{ cubic feet per second;}$$

where A = area of hole in square feet,
h = head of water in feet over hole.

The revolutions per minute of the fan were measured by a counter attached to the shaft, and the lift was determined by means of a staff fastened to a float in the lower tank. The staff was graduated in feet and decimals of a foot, and was applied to a water-gauge glass connected with the discharge-pipe. In order to take account of the residual velocity of the water in the discharge-pipe in estimating the lift; the tube with which the water-gauge was connected had a bend whose extremity met the water flowing in the discharge-pipe; consequently the water in the gauge-glass stood at the same height as the water issuing from the discharge-pipe. The engine was supplied with steam from a portable boiler, into which the feed-water was injected by a hand-pump. During an experiment the speed of the engine was regulated by an observer, so as to maintain a constant head of water in the measuring tank, and consequently insuring a uniform discharge from the pump. An experiment was continued until 30 gallons of water were evaporated in the boiler, and the time required to accomplish this was accurately noted. Then the number of lbs. of water raised by the pump per minute, divided by the number of lbs. of water evaporated in the boiler per minute, is proportional to the efficiency of the pump. These experiments were repeated for different discharges, and tabulated in the following form:—

TABLE 1.

Gallons discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. raised per lb. of Water evaporated.	Revolutions per Minute.	Remarks.
..	5·667	..	..	305	Appold's fan in circular casing.
745	6·000	44,886	7,779	363	
879	6·250	54,937	8,244	380	
989	6·666	65,936	11,883	393	
1,153	7·000	80,710	11,385	416	

The casing round the fan was next altered from the circular to the spiral form, as is indicated by the dotted lines in Plate 6, Fig. 4, by fitting wooden blocks inside; and a fresh series of experiments was now made under circumstances resembling the former set as much as possible. The following are the results, tabulated in a similar form:—

TABLE 2.

Gallons discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. raised per lb. of Water evaporated.	Revolutions per Minute.	Remarks.
..	5·750	..	..	320	Appold's fan in spiral casing.
577	6·500	37,505	8,960	346	
746	6·925	51,600	10,809	363	
878	6·750	59,265	11,264	368	
999	7·085	70,029	12,088	387	
1,150	7·750	89,125	13,248	403	
1,288	8·333	107,329	15,996	423	

Thus, by comparing the first and second tables, it will be noticed how greatly the spiral casing has improved the efficiency, and also increased the discharge, the boiler pressure remaining the same. With the same casing, but another fan, designed on the principles laid down by Rankine in his "Applied Mechanics," and also advocated by Glynn in his treatise on Water Power, some experiments were made similar to the preceding ones.

The following tables show the results of these experiments:—

TABLE 3.

Gallons discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. raised per lb. of Water evaporated.	Revolutions per Minute.	Remarks.
..	5·500	..	..	300	**Rankine's fan in circular casing.**
578	5·925	34,200	7,203	316	
741	6·167	45,695	8,556	335	
880	6·333	55,733	8,377	348	
993	6·583	65,372	10,748	355	

TABLE 4.

Gallons discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. raised per lb. of Water evaporated.	Revolutions per Minute.	Remarks.
..	5·416	..	..	300	**Rankine's fan in spiral casing.**
580	6·333	36,731	9,675	324	
743	6·667	49,528	10,857	334	
879	7·000	61,530	11,692	343	
996	7·333	73,036	12,954	353	

These results prove that Rankine's fan is far inferior to that of Appold. The blades of this fan were for half their length, from the centre outwards, similar to those of Appold; but for the remaining half of their length they curved forwards in the direction in which the fan revolves, and ended in radial tips (Plate 6, Fig. 6). This method of estimating the efficiency of a pump is by no means an accurate one; but in altering a pump it is a convenient way of determining whether the alteration has proved a success or the reverse.

A new casing was now designed, of a spiral form (Plate 6, Fig. 7), and a fresh series of experiments undertaken. These experiments were of a much more elaborate nature than those just described, and as it may make the deductions from them more easily understood, their general arrangement will be described. In order, as far as possible, to insure a constant lift, the pump was supported on the side of a large barge, and the engine for the purpose of driving it was placed in the bottom. The power transmitted to the pump was estimated by the dynamometer used by Messrs.

Eastons and Anderson at the Royal Agricultural Society's shows. The method of measuring the amount of water raised by the pump described in the former experiments was repeated in this instance; the water being raised from the Thames, in which the barge was floating, and discharged back into it through the measuring tank. The lift was measured by taking the difference of the levels of the water in the river and that in the discharge-pipe, as shown by two gauge-glasses. The revolutions of the pump were indicated by a counter attached to the pump-shaft. A number of experiments were made upon this pump, and the results tabulated as follows:—

TABLE 5.

No. of Experiments.	Gallons of Water discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. indicated per Minute.	Revolutions per Minute.	Efficiency per Cent.	Corrected Efficiency per Cent.
1	1,012	14·67	148,461	298,438	392	49·74	58·57
2	1,108	14·70	162,875	317,158	394	51·35	59·99
3	1,197	14·65	175,364	332,136	395	52·80	61·08
4	1,280	14·70	188,160	343,754	398	54·74	62·99
5	1,350	14·75	199,128	357,194	399	55·75	63·78
6	1,431	14·75	211,073	374,954	400	56·20	63·95
7	1,501	14·70	220,650	388,897	402	56·69	64·16
8	1,568	14·75	231,280	404,737	403	57·01	64·29
9	1,630	14·80	241,240	409,612	404	58·90	66·19
10	1,695	14·75	251,987	419,790	405	60·17	67·18
11	1,753	14·80	259,450	435,630	406	59·42	66·39
12	1,012	17·40	176,088	370,458	424	47·53	54·06
13	1,108	17·20	190,576	388,316	425	48·97	55·56
14	1,197	17·20	205,884	404,156	427	51·09	57·33
15	1,280	17·30	221,440	417,214	428	53·08	59·51
16	1,350	17·30	233,550	433,054	429	53·93	60·19
17	1,431	17·40	248,994	447,552	431	53·63	61·86
18	1,501	17·40	261,174	460,512	432	56·71	62·47
19	1,568	17·40	272,832	471,552	433	57·86	63·97
20	1,630	17·60	286,880	479,810	434	59·79	65·98
21	1,695	17·60	298,310	486,050	435	61·37	67·64
22	1,753	17·60	308,528	494,210	436	62·43	68·68
23	1,012	11·81	119,517	238,603	..	50·09	..
24	1,197	11·80	141,246	268,970	..	52·51	..
25	1,350	11·83	159,681	297,829	..	53·61	..
26	1,501	11·83	177,568	321,918	..	55·16	..
27	1,630	11·92	194,196	341,127	..	56·93	..
28	1,753	12·00	210,360	357,007	..	58·92	..
29	2,029	12·33	250,175	416,957	..	60·00	..
30	2,301	12·12	278,881	463,268	..	60·13	..
31	2,544	12·17	309,604	503,759	..	61·46	..
32	2,765	12·17	336,500	553,346	..	60·80	..
33	2,933	12·75	373,867	583,870	..	64·04	..

Some experiments upon a vertical-spindle centrifugal pump will now be described.

The shaft or spindle in these pumps is vertical, as is shown in Plate 6, Fig. 8, and the fan revolves in a horizontal plane. Outside the fan is a circular casing attached to the bottom of a wrought-iron tube. The water enters the fan on one side only—in this case below—and is discharged into the casing; from thence it is carried in the wrought-iron tube to the height required, and is discharged through the orifice in the side. The wrought-iron tube both performs the office of a discharge-pipe, and serves as a support for the bearings of the vertical shaft. Above the fan, and attached to the casing, are six guide-blades, shown in section in Plate 6, Fig. 10 and dotted lines in Fig. 8, which receive the water escaping from the fan with a high tangential velocity, and conduct it up the vertical tube. In order to render the explanation of this pump more lucid the working parts of the fan are shown in black when they occur in section, whilst the stationary parts of the case are indicated in the ordinary way. In this form of pump the vertical pressure upon the fan arising from the column of water over it is entirely removed : *ff* are two holes, 1 inch in diameter, in the top of the fan, which admit the water into the space between the support of the centre bearing and the fan, and consequently the pressures on both sides of the fan are equalised. The Appold fan, used in the experiments upon this pump, is shown in Fig. 9, and the one made upon Rankine's principle was similar to that in Fig. 6. The pump was placed on the side of the barge in the same position as the pump last described, and the experiments were carried out in an exactly similar manner, and the results obtained are tabulated as follows :—

TABLE 6.

No. of Experiment.	Gallons discharged per Minute.	Lift in Feet.	Foot-lbs. raised per Minute.	Foot-lbs. indicated per Minute.	Revolutions per Minute.	Efficiency per Cent.	Remarks.
1	3,079	8·1	249,399	559,600	206	44·3	Appold's fan.
2	3,343	„	270,783	576,460	208	46·9	
3	3,578	„	289,818	617,850	210	47·0	
4	3,821	„	309,501	674,600	214	49·9	
5	4,252	„	344,412	729,900	217	47·2	
6	4,437	„	359,397	766,830	218	46·6	
7	4,634	„	375,354	745,830	220	50·3	
8	4,810	„	389,610	795,700	220	48·9	
9	5,074	7·1	360,254	777,050	215	45·3	
10	3,079	6·2	190,898	503,000	163	37·9	Rankine's fan.
11	3,343	„	207,266	554,500	165	37·3	
12	3,578	„	221,836	578,000	165	38·3	
13	3,821	„	236,902	610,750	166	38·7	
14	4,042	„	250,604	656,750	167	36·6	
15	4,252	„	263,624	680,600	168	39·6	

These experiments also show the great superiority of Appold's fan over that proposed by Rankine.

The dynamical forces, produced in the centrifugal pump when it is in motion, will now be considered; and afterwards it will be shown how the theoretical investigations are supported by the experiments.

There are two totally different conditions in which a centrifugal pump may be situated while it is rotating. One in which it is revolving just fast enough to raise the water up to the discharge-pipe, and no further; and another in which it is revolving slightly faster, and discharging water out of this pipe. In the first case there is only centrifugal force, which is produced by the water in the fan rotating, that maintains the column of water in the discharge-pipe. In the second case this force is still produced, but in addition to it another, which may be called the force of impact, or in other words, the force with which the blades of the fan impinge against the water discharged by the pump.

The centrifugal force in the first case may be calculated as follows:—Assuming that the fan is a cylinder of water; every particle of this water as it rotates exerts a force outwards from the centre; consequently the force exerted at the circumference, or that which maintains the head in the discharge-pipe, is the sum of the forces of all the particles from the centre of the fan to the circumference. This force is given in lbs. per square inch by the formula

$$F = \int_0^R \frac{p\,x\,d\,x}{g}\,\omega^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Integrating this expression,

$$F = \frac{p\,R^2\,\omega^2}{2\,g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

p = weight in lbs. of a column of water 1 square inch in section and 1 foot long;
R = radius of fan in feet;
ω = angular velocity of fan;
g = dynamical force of gravity.

Now since $R\,\omega = v$, where v = velocity of circumference of fan, by replacing $R^2\,\omega^2$ by v^2 in equation 3, it becomes

$$F = \frac{p\,v^2}{2\,g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now supposing that the head supported by the fan, while it is rotating with a tangential velocity v, be h, then the pressure at the base of the column is $p\,h$, but by the ordinary formula of dynamics

$$h = \frac{v^2}{2\,g};$$

therefore

$$p\,h = \frac{p\,v^2}{2\,g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

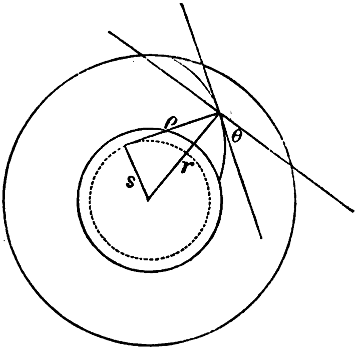
Thus by equations 4 and 5,

$$F = p\,h.$$

Therefore a fan, when rotating, will support a column of water the velocity due to whose height is equal to the tangential velocity of the circumference of the fan. This conclusion is fully borne out by the experiments, when corrections are made for the axle of the pump displacing a small quantity of water, and thus reducing to a slight extent the centrifugal force. In the case of the vertical-spindle pump (Plate 6, Fig. 8), a large correction has to be made in consequence of there being fixed ribs to support the lower bearing of the vertical shaft, and these, preventing the water contained beween them from rotating, reduce the centrifugal force to a great extent.

In the second case, in which the pump is supposed to be discharging water, the calculation of the centrifugal force is a much more complicated process than in the previous instance. Assuming that the blades of the fan are involutes of a circle whose radius is s (Fig. 1), and ρ be the radius of curvature of the involute at any point whose distance from the centre of the fan is r. Assum-

FIG. 1.



ing also that a particle of water moves in a curve similar to that of the blades—which is evidently the case. Then calling v the velocity of the water through the fan relatively to it, and ω its angular velocity, the linear velocity of a particle of water is given by the formula

$$V = r\omega - v\cos\theta \qquad (6)$$

θ being the angle indicated on the Fig., or $\cos\theta = \frac{\rho}{r}$.

Substituting for $\cos\theta$ its value, then

$$V = r\omega - v\frac{\rho}{r} \qquad (7)$$

Now the centrifugal force of a particle at the distance r from the centre, and moving with the velocity V, is

$$F = \frac{p V \omega}{g} d r\ ^{1} \qquad (8)$$

Putting in for V its value in equation 6,

$$F = \frac{p}{g}\omega\left(r\omega - v\frac{\rho}{r}\right)dr \qquad (9)$$

Now calling R and R′ the external and internal radii of the fan, and integrating expression 9 between these limits,

$$F = \frac{p}{g}\int_{R'}^{R}\left(r\omega^2 - v\omega\frac{\rho}{r}\right)dr \qquad (10)$$

but $\rho = \sqrt{r^2 - s^2}$;

substituting this in the last expression,

$$F = \frac{p}{g}\int_{R'}^{R}\left(r\omega^2 - v\omega\sqrt{1 - \frac{s^2}{r^2}}\right)dr \qquad (11)$$

Expanding the second term,

$$F = \frac{p}{g}\int_{R'}^{R}\left\{r\omega^2 - v\omega\left(1 - \frac{1}{2}\frac{s^2}{r^2} - \frac{1}{8}\frac{s^4}{r^4}\right)\right\}dr \qquad (12)$$

---

[1] This expression is not strictly correct, but is a near approximation.

$$F = \frac{p}{g}\left\{\frac{R^2 - R'^2}{2}\,\omega^2 - v\,\omega\left[R - R' + \frac{1}{2}\,s^2\left(\frac{1}{R} - \frac{1}{R'}\right) + \frac{1}{24}\,s^4\left(\frac{1}{R^3} - \frac{1}{R'^3}\right)\right]\right\} \quad . \; . \; . \; . \; . \; . \quad (13)$$

which is the whole centrifugal force exerted at the circumference of the fan in lbs. per square inch. The second force exerted in this case is the force of impact. It is estimated by the maximum tangential velocity generated in the water passing through the fan, which takes place just as it is escaping at the circumference. The reason advanced for the assertion that this force can be estimated by the tangential velocity produced, is that no other force can produce this velocity. The centrifugal force just calculated can only produce a radial force or a radial velocity, but can in no case produce a tangential force or a tangential velocity. This latter force can only be made use of by gradually reducing the velocity of the water issuing from the fan, and this condition is effected by the spiral casing and conical discharge-pipe, which will be referred to presently, and can be easily calculated by multiplying v by cosine θ', the angle made by the blade of the fan at its outer extremity, with the tangent to the fan; and subtracting this from V, the velocity of the circumference, the absolute tangential velocity of the water leaving the fan is obtained, viz.:—

$$v' = V' - v\cos\theta' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

The head then due to this velocity is given by the formula

$$H_2 = \frac{v'^2}{2\,g} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (15)$$

This, in other words, is the height that the water would rise, supposing that there was no friction to impede it. Now the centrifugal force has been estimated in lbs. per square inch; but by dividing it by 0·434 it is reduced to feet head of water. Then by adding these two heads together the theoretical height to which the pump lifts the water is obtained, *i.e.*,

$$H + H_2 = \frac{F}{\cdot 434} + \frac{v'^2}{2\,g} \quad . \; . \; . \; . \; . \; . \; . \quad (16)$$

This theoretical lift is always greater than that deduced by experiment, and it is only in a perfect pump that these two lifts would coincide. Consequently, if the practical lift be divided by the theoretical lift, and the result multiplied by 100, the percentage efficiency of the pump is obtained.

These calculations are worked out for the last series of experiments upon the spiral-cased Appold pump, and the results tabulated as follows:—

TABLE 7.

No. of Experiment.	Angular Velocity, ω.	ω^2.	$0·218\ \omega^2$.	Velocity through Fan, v.	$0·316\ v\ \omega$.	$0·218\ \omega^2 - 0·316\ s\ v\ \omega$.	Centrifugal Force in Feet Head, H.	Velocity due to Impact, $R\ \omega - v \cos \theta'$.	Head due to Impact, H_2.	Head by Experiment, H_1.	$H + H_2$.	Efficiency, $\frac{H_1}{H + H_2}$.
1	41·04	1,684	368·1	2·699	35·05	333·05	10·32	28·573	13·50	14·67	23·82	61·12
2	41·24	1,701	370·8	2·955	38·56	332·24	10·30	28·469	12·66	14·70	22·96	64·02
3	41·35	1,710	372·8	3·192	41·76	331·04	10·26	28·316	12·53	14·65	22·79	64·32
4	41·67	1,736	378·4	3·413	45·00	333·40	10·33	28·339	12·55	14·70	22·88	64·24
5	41·77	1,745	380·4	3·600	47·58	332·82	10·32	28·229	12·45	14·75	22·77	64·78
6	41·88	1,754	382·4	3·816	51·01	331·39	10·27	28·196	12·42	14·75	22·69	65·00
7	42·08	1,771	386·1	4·000	53·27	332·83	10·32	28·065	12·30	14·70	22·62	65·25
8	42·19	1,780	388·0	4·182	55·82	332·18	10·30	27·882	12·14	14·75	22·44	65·73
9	42·30	1,789	390·0	4·349	58·21	331·79	10·29	27·882	12·14	14·80	22·43	65·91
10	42·40	1,798	392·0	4·520	60·38	331·62	10·28	27·789	12·07	14·75	22·35	66·22
11	42·50	1,806	393·7	4·673	62·86	330·84	10·26	27·712	11·99	14·80	22·25	66·51
12	44·39	1,970	429·5	2·699	37·92	391·58	12·33	31·126	15·14	17·40	27·47	63·30
13	44·49	1,979	431·4	2·955	41·61	389·79	12·28	31·046	15·06	17·20	27·34	63·36
14	44·70	1,998	435·6	3·192	45·16	389·44	12·27	30·869	14·89	17·20	27·16	63·33
15	44·81	2,008	437·7	3·413	48·40	389·30	12·26	30·732	14·75	17·30	27·01	63·68
16	44·91	2,017	439·7	3·600	51·16	388·54	12·24	30·621	14·65	17·30	26·89	64·34
17	45·12	2,036	443·8	3·816	54·49	389·31	12·26	30·465	14·49	17·40	26·75	65·04
18	45·23	2,046	446·0	4·000	57·26	388·74	12·24	30·465	14·49	17·40	26·73	65·09
19	45·33	2,055	448·0	4·182	59·99	388·01	12·22	30·359	14·40	17·40	26·62	65·32
20	45·44	2,065	450·2	4·349	62·54	387·66	12·21	30·276	14·32	17·60	26·53	66·33
21	45·54	2,074	452·1	4·520	65·06	387·04	12·19	30·181	14·18	17·60	26·37	66·74
22	45·64	2,083	454·1	4·673	67·50	386·60	12·18	30·104	14·15	17·60	26·33	66·84

By comparing this with Table 5, it will be noticed that the theoretical efficiencies are considerably higher than those deduced by experiment. This is owing to the friction of the bearings of the pump, and of the strap by which it is driven; a small amount is also due to the outer sides and edges of the fan revolving in the water, not having been subtracted from the power indicated by the dynamometer. Some experiments were afterwards made in order to determine this friction, and it was found to amount to about 45,000 foot-lbs. per minute. The second column of efficiencies in Table 5 is obtained by making the correction.

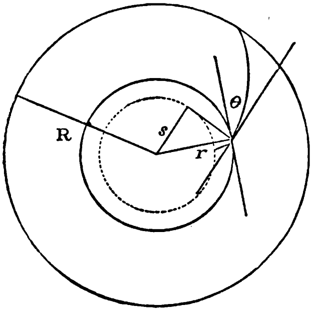
The slight discrepancies that are now found to exist between the theoretical and experimental methods of determining the efficiencies are within the limits of observation, as the experiments to determine the loss by friction were not made at the same time, or with the same pump as those tabulated above.

Some of the practical advantages of being able to calculate the efficiency of a centrifugal pump theoretically may here be mentioned. Since the efficiency is the lift as measured by experiment divided by that deduced by calculation, the more the latter can be reduced relatively to the former the greater is the efficiency of the pump.

The first principle to be attended to in effecting this condition is to avoid giving sudden shocks to the water, a principle which is ably discussed by M. Combes.[1] This is done in the fan by designing the blades so as to enter the water in a direction tangential to their surface at their inner edges; and at the same time having their outer edges so as to leave the water moving in a direction as nearly as possible tangential to the circumference of the fan.

The internal angles vary both with the lift and discharge with which the pump is intended to work, and their value can be found in the following way:—Assuming, as before, that their form is an involute of a circle, which is the best curve in consequence of its property of allowing a constant area of passage between the successive blades, and thus admitting of no change of velocity in the water whilst traversing the fan:

Let R = external radius of fan;
r = internal radius of fan;
ω = angular velocity of fan;
s = radius of generating circle of involute blades;
v = velocity of water through the passages of fan in feet per second;
v' = radial velocity of water entering the blades;
$V' = r\omega$ = tangential velocity of the internal circumference of fan in feet per second;
θ = angle made by the blades with the internal circumference of the fan.



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[1] "Recherches théorétiques et expérimentales sur les roues à réaction ou à tuyaux."

Then referring to Fig. 2.

$$\sin\theta = \frac{s}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

and the condition that the blades should enter the water tangentially is evidently

$$\tan\theta = \frac{v'}{V'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Eliminating θ between equations 17 and 18, an equation is obtained for determining s, viz.,

$$s = \frac{v' r}{\sqrt{V'^2 + v'^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

If then the blades of the fan be described with a generating circle, having a radius equal to that given by the preceding formula, they will cut the water in a tangential direction. This formula involves, first, the radial velocity of the water entering the fan, which is easily calculated from the required discharge. The best velocity for the water to flow through the passages of a fan is from 6 to 8 feet per second. Next, the internal radius, which is generally made half the external. And, lastly, the velocity of the internal periphery of the fan. This is given by the following formulæ—

$$V = r\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

$$\omega = 9\frac{\sqrt{h}}{R} \cdot gp \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

A general equation which unites all the variables in a centrifugal pump will now be considered. Assuming at present that the pump has a spiral case, and that its mean theoretical efficiency be 64 per cent., as it was found to be by experiment; then the lift under which the pump is to work must be this percentage of the theoretical lift. Putting this condition into symbols, in the general equation

$$\text{Lift} = 0 \cdot 64\left[\frac{p}{g \times \cdot 434}\left\{\frac{R^2 - r^2}{2}\omega^2 - v\omega\left(R - r + \frac{1}{2}s^2\left(\frac{1}{R} - \frac{1}{r}\right)\right)\right\} + \frac{(V - v)^2}{2g}\right]. \quad . \quad . \quad . \quad (22)$$

But $V = R\omega$.

Substituting this in equation 22, an equation is found involving R, ω, v, and lift, any three of which being known, the fourth can be determined. This equation is of great practical value; for if, for instance, it is required to be known how fast a pump of given dimensions ought to be driven, so as to deliver a given quantity of water at a given lift, it is only necessary to put in the given dimensions, the discharge required, and the lift, and to solve the quadratic equation for ω, which gives the angular velocity at once. The general equation is applicable to all centrifugal pumps, but the theoretical efficiency of each kind must be determined before it is introduced into this equation, if great accuracy is required; but for all practical purposes the co-efficients 0·60 or 0·64 are sufficiently accurate.

The next thing to be borne in mind is to proportion the passages throughout the pump, so as to have a gradually increasing velocity in the water until it arrives at the circumference of the fan, and then to have a gradually decreasing velocity until it issues from the discharge-pipe. This condition is effected by having a conical end to the suction-pipe; and what is much more important is to have a spiral casing surrounding the fan. The importance of the last detail is shown most conclusively by the first series of experiments with the circular and spiral cases.

The form of the casing should be an Archimedian spiral, which has the property that the water flowing round the case moves with the same velocity as that issuing from the fan. The casing should then gradually open out into the discharge-pipe, and, if practicable, a conical adjutage should be added, similar to those described by Rittinger.[1]

The same conditions are as nearly as possible fulfilled in the vertical-spindle pump previously described. Below the fan is a conical opening which produces a gradually increasing velocity in the water entering the fan. The water escaping from the fan is gradually turned into an upward direction by the guide-blades over the fan, and is at the same time checked in its velocity in consequence of the apertures between the guide-blades being smaller near the fan than above. The vertical-spindle pump was first tried without any guide-blades over the fan, and the maximum discharge obtained with an 8 HP. engine was 1,500 gallons per minute. Six guide-blades, similar to those in Plate 6, Figs. 8 and

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[1] "Centrifugal-Ventilatoren und Centrifugalpumpen."

10, were then put in, and the maximum discharge, with the same engine and same boiler pressure, amounted to 5,000 gallons per minute. This fact, is sufficient to show how important it is to make use of the velocity of impact, which by Table 7 produces a force greater than that of the centrifugal force. Professor Rankine[1] in discussing centrifugal pumps states that guide-blades are unnecessary, and even useless; but it seems that the results arrived at by experiment, if not those deduced by theory, clearly prove how important guide-blades are for the attainment of high efficiencies with the vertical-spindle centrifugal pump.

By referring to the column of calculated centrifugal forces in Table 7, it will be observed that the faster the fan rotates—the lift remaining constant—the smaller is the centrifugal force. This seems to be a paradox at first sight, but the reason is evident. As the discharge increases, the velocity of the water in the casing more nearly approaches that of the water leaving the fan; consequently the efficiency of the pump improves, and the theoretical lift diminishes, and with it the centrifugal force.

A remarkable property of centrifugal pumps may be mentioned, which is illustrated very clearly by the preceding experiments, viz., that a small increase in the number of revolutions of the pump, when it has begun to discharge, produces a very large increase in the delivery. Thus in Table 5 the difference in discharge between experiments 1 and 11 is 741 gallons per minute, and a small increase of only fourteen revolutions; or in other words, while the discharge is nearly doubled the revolutions are only increased by $\frac{1}{28}$. This property has been made use of by Professor James Thomson as a speed-indicator,[2] and has proved successful.

In conclusion, the whole aim of this Paper has been to show that the calculated efficiency is identically the same as that deduced by experiment. Most people have tried to calculate the friction in the pipes and passages in these pumps to effect this, but they have been unable to do so. The Author, however, has proceeded entirely on hydrodynamical principles, and has merely taken the velocities generated in the water, by which means the friction through the passages of the pump and the pipes has been eliminated from the calculations, in consequence of the velocities through them being directly affected by the friction, and these were determined by experiment. The only friction it was necessary to measure was that of the strap required to drive the pump, and the friction in the bearings, and of the outside of the fan revolving in the water. This latter friction was ascertained by driving the pump at a speed of about 410 revolutions per minute, which corresponded nearly with a mean of the revolutions run during the previous experiments, and, as has been before stated, amounted to about 8 per cent. This is only an approximation; but owing to the great difficulty in maintaining a constant speed in a pump when it is not discharging, a more accurate series of experiments was not made.

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[1] Rankine's "Applied Mechanics;" article on Centrifugal Pumps.

[2] "Mechanics' Magazine," January 1851.

MEMOIRS OF DECEASED MEMBERS.

Sir CHARLES WHEATSTONE,[1] born in February 1802, was the second child of a family of two sons and two daughters, his father being a musical instrument manufacturer in Gloucester. In 1806 his parents removed to London, where the father established himself in business, which he carried on for some years at 128 Pall Mall, and in addition gave instruction on the flute and flageolet. Charles Wheatstone's instruction commenced at an early age, for he was sent to a village school near Gloucester before he was brought to London, at which date he was able to read "verses out of the Bible." A child of under four years who can read is generally less gifted than the average at forty. But this was not the case with Charles Wheatstone; the early power of memory exhibited in this instance went on increasing until it developed into the mental power of the physicist.

After he was brought to London he was sent to a school at Kennington, kept by a Mrs. Castlemaine, who was astonished at the progress made by young Wheatstone while under her care. This progress and his love of learning had great allies in the naturally nervous and timid nature of the child. Most children at times hide their faces in their books, but young Wheatstone hid his there always, and used his eyes in conning their contents. At this school he acquired the character of being unsociable, from his disinclination to join in the sports of his schoolfellows, whilst timidity and nervousness were at the bottom of it.

Later on he was sent to pursue his studies at an establishment which appears to have been unworthy of the pupil, for in addition to youthful disputes with his teacher over what he was taught, which he considered inaccurate and deficient, he got utterly disgusted with the school, and ran away. Those who in after life have known the extremely hesitating and cautious nature of Charles Wheatstone, can well estimate how enormous must have been the effort in the child to make up his mind to this step. The history of his escape is not romantic; he got as far as Windsor, and was brought back again.

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[1] *Vide* also Proceedings of the Royal Society, vol. xxiv., p. xvi., and obituary notices in the journals at the time of his decease.

At another school, conducted on the Lancastrian principle, in Vere Street, he, in 1813, in the half-yearly reports got the character of "application moderate," yet he made considerable progress, for he carried off a gold medal in competition for "French language," the other competitors being considerably his seniors in date of study, as well as in age. But a rule of the school was, that the happy victor should recite a speech on the occasion of the prizes being distributed. This young Wheatstone could by no threats or coaxing be persuaded to attempt, and his obstinacy was punished by the application of a sound rule, "no speech, no medal."

About the year 1816 he was placed with his uncle and namesake, who carried on business as a music-seller at 436 Strand. The novelty of business may have interested the lad for a short time; but this did not last, and the uncle complained that he neglected work to pore over books. Another unbusinesslike habit was to shut himself up in an attic, and be quite happy if only he was not disturbed. Seeing the evident bent of the lad's mind, and despairing of success in opposing it, the father sensibly encouraged him in the pursuit of his studies, took him away from his uncle, and procured him the loan of books from the Society of Arts in the Adelphi. About 1817 he translated a considerable portion of some French poetical works. He wrote also two songs, which, fearing his uncle would not look at as his, he gave to Omera, who took them, offered them as his own composition, to the uncle, by whom they were published and appreciated, in ignorance of their real authorship. He was only fifteen when he wrote some lines on the Lyre, since quoted in an engraving by Bartolozzi.

In 1819, when Wheatstone was seventeen years old, he exhibited in Pall Mall some highly interesting practical experiments in acoustics. Then he opened a Museum at the lower great room, Spring Gardens, where he showed the most novel and startling phenomena. Among these were his "Central Diaphonic Orchestra," by which he obtained an immense augmentation of the tones of musical instruments in richness and power, and an "Œdephone," an equivalent substitute for a band of wind instruments when played in his diaphonic orchestra. But the prettiest experiment was the "Acoucryptophone" (he was very partial to hard words) or Enchanted Lyre. This Enchanted Lyre was included in the Loan Collection of Scientific Apparatus at South Kensington in 1876 (No. 701A in the catalogue). It consists of a hollow box of the shape of an elegant antique lyre. This was suspended from a wire passing through the ceiling of the room and hanging upon the sounding board of a piano or other musical instrument in some upper storey. When the instrument was struck the vibrations passed down the wire and became audible in the lyre. The instrument was not heard, and the deception was complete. Ackerman's "Repository" for March and May 1822 contains a full account of all that Wheatstone did on this occasion. In 1823 Charles Wheatstone returned to the Strand, and, on the death of his uncle shortly afterwards, he, in conjunction with his brother, took to the business, with which he was connected for about six years, although he never took an active part in it. In the same year he published, in Thomson's "Annals of Philosophy," a Paper entitled "New Experiments on Sound," which is rich in experimental facts concerning vibrations of chords, rods, and surfaces. The attention of physicists was directed to it, and it was reproduced in France in the "Annales de Chimie," and in Germany in "Schweiggers Jahrbuch." He was very proud when his paper was translated into foreign languages. There is no encouragement so great as being appreciated.

The peculiarity of Wheatstone's mind seems to have been not to trust to anything but actual experiment. He sought diligently after new facts, but quite as diligently after new means of seeking them. He knew of the existence of waves, but he wanted to see them in all their variety, and, seeing them, he wanted to learn more about them. "New Experiments in Audition" appeared in 1827 in the "Quarterly Journal of Science," and in the same year a Paper describing his beautiful invention the "Kaleidophone." This consists of a steel wire fixed in a firm base and surmounted by a bead of silvered glass. When the rod is set in vibration the reflection of a light point (from a window or candle) in the glass bead is seen by persistence on the retina to follow the most beautiful and symmetrical paths. In compound vibration, by an appropriate displacement, the section of the rod being suitable, all ratios of vibration are obtained. This instrument he modified by means of a mechanism which kept the rod in action, by a combination of rectangular vibrations of any given ratio.

In all this the direct outcome of the music-shop was carried by Wheatstone out of its sphere, into those higher principles which underlie the science of sweet sounds. But the music-shop still claimed him, and he conscientiously thought that he devoted a good deal of time to its interests. He travelled also on business affairs, but it is doubtful whether this was not done as a matter of duty, and it was always distasteful. But his conscience must have been lightened by the knowledge that his suggestions and inventions returned a profit to the concern, which more than compensated for any disinclination to the drudgery of shop life. The award which (like his schoolmaster in younger days) his brother might have given, "application moderate," would perhaps have been strictly untrue, for Wheatstone worked all this time bravely, and well and earnestly; but it was work which a higher class audience only could appreciate.

In 1828 appeared in the "Quarterly Journal of Science" his admirable Paper on "Resonance." In 1829 the house in the Strand was pulled down for alterations in the neighbourhood, and with this Wheatstone's connection with the music-shop virtually ceased. His brother removed to 20 Conduit Street, where he carried on the business. In 1831 Charles Wheatstone summoned courage to read a Paper on "Transmission of Sound through Solids" before the Royal Institution. In this lecture he showed the transmission of sound through wires and rods, and probably brought before a more scientific audience than formerly his "Enchanted Lyre." At the autumn meeting of the British Institution in the same year he gave an interesting experimental proof of Bernoulli's theory of the vibrations of air in musical instruments.

From this date Wheatstone's life became that of an earnest and unassuming, quiet and hard-working, man of science. To his unconquerable repugnance to public speaking is perhaps to no small extent due the fact, that he cultivated so assiduously actual experimental inquiry. Had he been eloquent, he might, and possibly would, have gone the road of many clever men, and degenerated into a mere lecturer. As it was, he clung to the last to actual experiment upon any subject in which he was interested. As a lecturer he was a failure: he has been caught more than once turning his back to his audience and mumbling to his diagrams; notwithstanding this, he read beautifully, and had a good, although not a powerful voice. Feeling that his place was the laboratory, and not the lecture-room, he gave up the attempt, and hence it was that Faraday and others brought his inventions and discoveries before public audiences.

In 1834 Wheatstone was appointed to the Professorship of Experimental Philosophy at King's College, where he delivered some lectures on "Sound." He, however, soon gave up the lecturing part, and, becoming afterwards engrossed in electrical matters, virtually held his post rather nominally than really. The first invention after his appointment to the Professorship was his beautiful rotating mirror, by which he determined the time the electric impulse, discharged from a Leyden jar, took to reach a point ¼ mile distant along a copper wire, and to jump across a small space of air. The greatest use, however, to which this apparatus was put was in the determination of the velocity of light by Foucault. From this date Wheatstone's attention was pretty well divided between Sound and Electricity. In 1835 he made a speaking machine, an india-rubber mouth before which the hand was manipulated, which produced such simple words as "rum," "mamma," &c. He did not, however, prosecute the subject far, and, after contributing a Paper "On the Various Attempts which have been made to imitate Human Speech by Mechanical Means,"[1] he appears to have let the subject drop.

The determination of the velocity of electricity naturally turned his attention to the subject of utilising travelling electricity as a means of communication. Much had been already done at an early date in crude attempts to effect this, notably by Stephen Grey in 1827, Dr. Watson in 1747, Sömmering in 1808, and others. On the Continent rapid strides were being made by Schilling, Sternheil, and Ganos, whilst in England inventors appeared to have been discouraged. This may to some extent have been due to the adverse opinion expressed by the Government as to the utility of telegraphs in general. In 1816 Mr. Francis Ronalds had invented an impracticable anachronism, in the form of a telegraph with frictional electricity, which he offered to the Government, who replied through the Secretary of the Admiralty that "telegraphs of any kind are now wholly useless, and no other than the one now in use will be adopted." Had the reply simply been that telegraphs of the kind suggested would be wholly useless, and that if nothing better were forthcoming the one in use would of necessity be retained, it would have been nearer the mark than this unhappy generalisation. Two men, however, began to take up this work on a rational basis at the same time. One was Wheatstone, led to it as a direct outcome of his velocity experiment; the other was Mr. W. F. Cooke, now Sir William Fothergill Cooke, Assoc. Inst. C.E., a young military man, who, returning from India on leave of absence, passed through Germany and saw such an invention in action. Wheatstone was plodding quietly on very scientifically, whilst Cooke, more practical, was casting about him how to turn the idea into money. At this stage mutual friends brought them together, and they combined their ideas in the form of a patent. To Wheatstone and Cooke the world owes the fact that the electric telegraph became a practical reality at an early date, whereas without the scientific and inventive ability of the one, and the sound business judgment of the other, telegraphy might, and in all probability would, have been long years before it attained the thoroughly useful form with which they endowed it.

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[1] *Vide* Report of the British Association for the Advancement of Science, 1835 Transactions of the Sections, p. 14.

In 1836 Wheatstone began to direct his attention to the subject of a submarine telegraph, but his plans were not matured until the year 1840. He then gave evidence before the Railway Committee of the House of Commons on the practicability of establishing a submarine line from Dover to Calais. In the autumn of the same year he prepared detailed drawings of the machinery and methods for making the cable, and the processes of laying, jointing, and underrunning. In 1844 Wheatstone carried out an experiment in Swansea Bay, where he submerged an insulated wire, and succeeded in telegraphing between a boat and the Mumbles lighthouse. Beyond the credit of being the inventor and constructor of the first practical telegraph instrument, there is also due to Wheatstone the honour of being the first to suggest and to design a submarine telegraph. The starting point of submarine telegraphy most unquestionably dates from this experiment in Swansea Bay, although it was six years later before his idea of joining France and England by this means was actually carried out in an improved manner by Mr. Brett and others.

It would occupy too much space to enumerate all the improvements and inventions made by Wheatstone in the domain of telegraphy. Two of his instruments are conspicuous: his A B C dial instrument found at the ends of every private telegraph wire in the kingdom; and his Automatic system, by which messages are sent at the rate of about 150 words a minute—the system by which the Post Office is enabled to get through the long columns of news it transmits for publication in the daily papers, besides the ordinary message traffic on the principal trunk lines of the country.

In scientific, as well as in practical, electricity Wheatstone's name will ever be remembered with respect. It was he who first devised a means (Wheatstone's bridge) of measuring quantitatively the resistance of a metallic circuit, a system by which all such resistance measurements are still made.

Amongst his studies and labours that of light came in for a full share. In 1835 he seems first to have seriously turned his attention to the subject, and read a Paper at Dublin, "On the Prismatic Decomposition of Electric Light,"[1] in which he made known the existence of bright lines in the spectrum of any metal when volatilised by the electric spark. His subsequent discovery of the stereoscope, and the train of reasoning which led to it, may be found in his Paper on "Binocular Vision." His "polar clock," used lately on the North Polar Expedition, consists of a Nicholl prism as an eye-piece and a plate of selenite as an object. The plane of polarisation of the sky being always 90° from the sun, if the instrument be directed to the North Pole, the position of the prism will require to be adjusted accordingly, in order to reproduce any neutralised or other given effect of the selenite plate. The account of this adjustment or rotation on its axis gives the hour of the day. Practically valueless where watches are cheap, this instrument on a polar expedition, were it possible to attain the highest latitudes, might be of the greatest value.

In cryptography, or the means of writing secret cipher, Wheatstone was unequalled. He not only invented a cryptograph which has never been deciphered, but succeeded in unravelling some of the cipher MSS. in the British Museum, which until then had been unintelligible.

There is scarcely a branch of applied science which Wheatstone's mind has not enriched. The great scope of his ideas was, in fact, occasionally a drawback, for, unlike the majority of men, he was unable to work steadily at one subject for a length of time. Something would occur to call into prominence momentarily a different subject, for which the first would for the time be laid aside. To this is due the fact that so many subjects remained unfinished when he died—subjects which had been in the interim worked out exhaustively by others. Of Wheatstone it may be said that he outlived his own work, which he saw taken up and completed or pushed farther by younger men.

Charles Wheatstone belonged to a race of scientific men which is fast disappearing. The traditions of conscientious hard work in which he had been born and bred, and the life of actual experimental investigation in which, up to the hour of his death, he passed his time, may have induced in his mind a contrast unfavourable and sometimes perhaps unfair towards the newer order of scientific men, whose attention is directed more to mathematical reasoning on already established experimental investigations, than in either verifying the older experiments, or in making new ones on their own account. He clearly saw that the earlier half of the present century had produced the facts which have revolutionised science, and he was perhaps severe in thinking that the second half of the century was producing the men who do little more than apply algebra to them.

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[1] *Vide* British Association Report, 1835. Transactions of the Sections, p. 11.

As a worker Wheatstone was industrious and original, and he kept steadily in view the purpose for which he laboured, that defined by Tredgold as the conversion, adaptation, and application of the great sources of power in nature for the use and convenience of man, an infinitely higher purpose than either satisfying an unreasoning curiosity to peep into the secrets of nature, or the mere desire to obtain patent-rights.

He was elected an Honorary Member of the Institution on the 2nd of March, 1875, "because of his distinguished attainments in physical science—of his numerous discoveries and inventions in acoustics, optics, electricity and magnetism—more especially of his profound and successful researches in the practical development of the electric telegraph, and of his many important modifications of the system, and appliances for transmitting intelligence through that agency."

Of his private life there is little to record, as it was most uneventful. He married on the 12th of February, 1847, at Christ Church, Marylebone, the daughter of a Taunton tradesman, a young lady of considerable personal attraction, who died in 1866, leaving him the task of bringing up five young children.

His death took place on the 19th of October, 1875, in Paris, whither he had gone to conduct some experiments on a telegraph receiving instrument which he had invented in the previous spring. He was buried at Kensal Green in the grave which contained the bodies of his wife and his brother and sister.

Mr. CHARLES FREDERICK BEYER, who died at his residence, Llantysilio Hall, in the county of Denbigh, on the 2nd of June, 1876, was the head of the well-known firm of Messrs. Beyer, Peacock, and Co., of Gorton, Manchester. He was born at Plauen, in the kingdom of Saxony, on the 14th of May, 1813, and his parents, who were in humble circumstances, supported themselves by hand-loom weaving. They were unable to give their children more than the usual education demanded by the State; and as they intended to train up their son Charles to follow their own occupation, he was, in due time, bound to a three years' apprenticeship. Early in life the lad had amused himself by making little models of buildings, to the delight of his mother, who imagined an architect in her son Charles. It happened, when he was about twelve years of age, that a young architect settled in Plauen, and, in order to nourish the taste which the boy exhibited, the hours not devoted to school were spent with the architect, who, in addition to giving lessons in drawing, taught arithmetic and geometry at a charge of about 4*s.* per quarter. So great was the progress made, that in a short time a drawing of a head was taken home and framed, being the first picture that adorned the wall of his father's parlour. The young architect removed from Plauen, and it chanced that, whilst the experiment was being made of training his pupil to the loom, the drawing above referred to was seen by a Mr. von Seckendorf, an eminent medical gentleman who had been called in to prescribe for an elder brother.

"Who was the artist?" asked this gentleman. "My son Charles," replied the father. "And what may your son Charles be doing?" "Oh, he is a weaver." "A weaver!" "Yes, a weaver; and I am very well content, for he is a good lad, and pleases his master well." "But," continued Mr. von Seckendorf, "he should go to Dresden to the Academy; there is a school just established—a Polytechnic School. I will see about it; I will speak to the Kreishauptmann" (the chief officer of the county). The youth's sketches and papers were accordingly sent to Dresden, and his name given in as soliciting to be admitted into the Polytechnic School. The father did not approve of this, for he knew not where the means were to come from to sustain his son in the capital for a period of four years; and great was his consternation when he received a summons to attend the chief officer, who wished to learn his intentions regarding his son.

As the sum of $30 (£4 10*s.*) per annum was given by the State towards educating each boy, he said that Charles might go and try for six months; the dread of offending, rather than his son's interest, prompting the reply. The apprenticeship was resigned when it became the wish of the high official, and Charles was sent to Dresden. It was here that the sort of metal of which he was made was first put to the test, and a severe test it was. He studied hard; and, as no pecuniary aid came from home, the pittance was small upon which he had to exist. On many days his dinners cost him the sum of three pfennings (less than one halfpenny), and as the six months drew to a close, he contemplated returning home. On consulting one of the professors, he was advised to struggle on, and as a small assistance he prepared papers for the use of the workshops and kept some of the time-books, for which service he received pay at the rate of $\frac{3}{4}$*d.* an hour.[1] He continued the struggle through the course of four years, and completed his studies; and during that period his expenses, including the stipend of $120, did not exceed $410, or £15 7*s.* 6*d.* per annum. From Dresden he removed to Chemnitz, where he remained two years, and worked in the machine shop of Mr. Haubold, receiving for the first year 6*s.*, and for the second, 9*s.* per week as wages. It was whilst employed at this establishment that he got into trouble through having unwittingly violated a rule of the works, by making a sketch of some machine which was in course of construction. This led to his being sent back to Dresden. On the journey, which he had to make on foot, he passed through a small town in which lay a criminal awaiting capital punishment. The harrowing tale was told to young Beyer, and such was his distress that (as he himself related) he passionately wished that it had been his own lot to suffer instead.

Through the influence of friends in Dresden, his little fault was condoned: he returned to Chemnitz to complete his term of service; and so satisfactory was the progress which he had made, that on its completion, which was in the summer of 1834, he received a sum of $300 (£45) from the Saxon Government, to enable him to visit England, and to report upon the improvements in machinery—chiefly with regard to the spinning of cotton. Of this sum he expended £25 in a suitable outfit, and the remainder for the expenses of the journey. He made the desired report upon cotton-spinning, and received for the information £10 from the mill-owners of Chemnitz, and some additional payment from the Saxon Government.

A joint-stock company for cotton-spinning was formed in Chemnitz, and he was solicited to undertake the management. A company was also formed for the like object in Dresden, and there, too, his services were sought. Both offers were however declined, and in the latter part of the year (1834), being then twenty-one years of age, he removed to Manchester, accompanied by Professor Schubert, of Dresden, by whom he was introduced to Messrs. S. Behrens and Co., the well-known merchants. Through Mr. Behrens, but not till after some delay,[1] he obtained an appointment with the firm of Messrs. Sharp, Roberts, and Co., in a subordinate capacity as draughtsman, at a rate of wages which, during the first year, was little more than nominal, and did not exceed 30*s.* per week in the second year. Here, notwithstanding his difficulties with regard to the English language, the readiness with which, as a mechanical draughtsman, he could put his ideas upon paper, speedily attracted the notice of Mr. Roberts, whose fertile inventive genius often outran his power to do the like. So strong was this faculty, that on one occasion Mr. Beyer, who happened to be present whilst Mr. Roberts's draughtsman was endeavouring, but without success, to sketch out a mechanical arrangement which Mr. Roberts had just conceived, showed by a few strokes of his pencil that he grasped his master's meaning; upon which Mr. Roberts exclaimed, "There is a man (speaking of his draughtsman) who can tell every word I say, but cannot put my ideas upon paper; and here is another (Mr. Beyer) who scarcely knows English, but who can not only understand but also put into shape all that I mean." Mr. Roberts now began to find out his great and valuable qualities, both as a mathematician and as a quick and true draughtsman; and as about this time Messrs. Sharp, Roberts, and Co. commenced to turn their attention to the manufacture of locomotive engines, it fell to Mr. Beyer's lot to carry out, under Mr. Roberts's instructions, this branch of their business, and in this way to lay the foundation of a reputation as a builder of locomotive engines which has become world-wide. Mr. Beyer had not the reputation of being an inventor, although he is believed to have been the first to suggest, in the construction of locomotives, the single straight plate inside framing; but his sound knowledge of elementary principles, his refined taste, his readiness as a draughtsman, his probity, and his untiring industry not only showed his fitness for his office, but soon secured for him a better position with his employers, and led to a close intimacy between Mr. Roberts and himself, which was greatly to their mutual advantage, since each had special qualities not possessed by, but exceedingly valuable to, the other. A large number of locomotives of a distinctive character and of excellent workmanship soon made their appearance upon the Dublin and Kingstown, Grand Junction, Great Western, and other English railways, and also upon various French and German lines, which proved to be eminently satisfactory in their performance. In the summer of 1843 Mr. Roberts retired from the partnership, and from that time until the spring of 1853, when Mr. Beyer's connection with the firm (then, as now, Messrs. Sharp, Stewart, and Co.) also terminated, he was the mechanical head of that establishment. It was during this period he was able to bring to bear upon locomotive design, that innate perception of mechanical fitness and that refined taste which have been so prominently shown in all his designs. After retiring from the service of Messrs. Sharp, Stewart, and Co., Mr. Beyer travelled for six or eight months in England,[1] and on the Continent. Shortly after his return from the latter, he entered into partnership with Mr. Richard Peacock, who was until then Locomotive and Mechanical Engineer to the Manchester, Sheffield, and Lincolnshire Railway Company. Thus was established the eminent engineering firm of Messrs. Beyer, Peacock, and Co., which, possessing the advantagê of Mr. Beyer's special qualities as above enumerated, and Mr. Peacock's practically acquired knowledge of the requirements of railway working, coupled with no ordinary share of ability in commercial matters, speedily took a position among the first to be found in this or in any other country.

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[1] To this period of his life belongs an incident which forcibly illustrates the severe training under which the future engineer grew up. "A benevolent lady of Dresden," Mr. Beyer said, "was in the habit of giving every Friday a good dinner to the two or three pupils of the Polytechnic School who had distinguished themselves most during the preceding week; and I can still recall how eagerly I strove week after week to be one of the chosen few, that I might not lose a meal which was almost necessary to my sustenance, so hardly was I obliged to live."

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[1] Mr. Sharp appears to have been at once struck with the signs of character and ability shown by the young applicant, and told him to come again on the following day. In the interval, however, he found that the proposal to introduce a foreigner into the works roused such a storm of opposition that he did not venture to persist; and when Beyer appeared he was obliged to tell him that he could not offer him an engagement. The deep chagrin of the young German was so evident that Mr. Sharp, partly mistaking its meaning, opened his purse and offered him a sovereign. Young Beyer respectfully but somewhat indignantly declined to receive it, saying, "It is work that I want." Mr. Sharp was so impressed by the words, and the look which accompanied them, that he resolved to brave all consequences, and engaged him on the spot. The anecdote is characteristic at once of the times and of Mr. Beyer's original and manly nature.

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[1] During this interval he conceived, and for a time seriously entertained, the notion of abandoning the profession, at least for a time, and embracing the career of a student; and it was with this object that he visited both Oxford and Cambridge on his tour. The masculine good sense, however, which (notwithstanding a vein of romance which he certainly possessed) was his chief characteristic, preserved him from what would at his age have probably proved a real mistake. He said to himself, as he sat on a gate from which he was watching the towers and roofs of Cambridge, "Beyer, you are a fool," and once for all gave up the pleasing dream.

Referring further to Mr. Beyer's special qualities as an engineer, it was said that "he had a highly developed perception of what was correct and suitable for the purpose in hand, which, combined with a natural taste for the beautiful and simple, gained for the engines which he turned out that well-merited renown which they enjoy; and when the engine 'Don Luiz,' was exhibited in London in 1862, the critic of the Art Union spoke in the highest terms of eulogy about its graceful and pleasing shapes."

In designing the workshops at Gorton Foundry, Mr. Beyer's powers of adapting means to the ends required were again prominently displayed, and leave but little room for doubt, that if he had chanced to follow his early bent he would have distinguished himself as an architect. The various sections of these works are almost exact counterparts of each other so far as the buildings are concerned, and have been so arranged as to admit of the gradual expansion and enlargement of the whole by the simple addition of other sections, without disturbing or altering the portions previously erected. In the production of most of the details of locomotive engines he also designed and adapted many special tools, with the well-known result of at once improving the character and reducing the cost of the work done. With these advantages the business of the firm rapidly increased in magnitude. Engines bearing Mr. Beyer's well-known impress are to be seen in nearly all parts of the civilised globe, and are in no small degree operating to refine the taste and instruct the skill of the mechanical engineering world. The results in other respects, it is to be presumed, were no less satisfactory. That this was so may be inferred from an entry in his diary on the anniversary of his fiftieth birthday, in the following words: "Have mercy upon me, O Lord, and grant that the goods Thou hast intrusted to my keeping may bear fruits to Thy honour and glory, through Christ Jesus;" and from the benefactions which he distributed so liberally during his lifetime, and which he has provided shall by no means cease now that he is gone.

The severe hardships with which Mr. Beyer had to struggle during his early career, made, it is believed, a considerable impression upon his character, and gave it an appearance of harshness, much more apparent, however, than real, which was sometimes keenly felt by youths who were seeking to be launched upon the world through him as an employer. He did not spare himself, and had but little forbearance with those who showed a disposition to shirk duty; "his bark was," however, "worse than his bite," and beneath this exterior was a kind and beneficent nature, which it may be said was often "generous to a fault," and was doubtless frequently imposed upon.

Mr. Beyer was never married, and his nearest living relative at the time of his death was an only sister. Besides replacing at his own cost the old parish church at Gorton by an entirely new one, and rebuilding, almost unaided, the schools and rectory connected therewith, he contributed largely towards the cost of erecting St. Mark's Church, West Gorton (the schools belonging to which were also built at his cost), and defrayed the greater part of the cost of rebuilding the church upon his estate at Llantysilio. By his will he left £3,000 for the augmentation of the income of the Vicarage of Llantysilio, and the sum of £10,000 for the erection of another church and parsonage not far from the Gorton Foundry, the schools for which he built upwards of twelve months before; and in addition to these sums he left legacies to various public institutions and charities, amongst which may be named the Manchester Infirmary, Manchester Grammar School, Manchester City Mission, Ardwick Industrial and Ragged School, British and Foreign Bible Society, &c., and also to some of his draughtsmen and domestic servants, amounting in all to about £25,000. After the disposal of his property in Denbighshire to his godson Henry Beyer Robertson, he left the residue of his estate for the benefit of Owens College, Manchester, towards the "foundation and endowment of professorships in science, one at least of which shall be a professorship of engineering in the said college." Here it may be mentioned that about sixteen years ago Mr. Beyer obtained an introduction to Professor Greenwood, now Principal of the College, and stated that, being familiar with the successful working of some of the German Polytechnic Schools, it had occurred to him that Owens College might with advantage develop such a school or department in connection with its scientific chairs; and he even then urged that a movement should be begun for extending and rebuilding the College on a larger and more appropriate site. He was thus the first to suggest the Extension movement, which has had such unexpected results, and was a munificent contributor to the Extension Fund, as the following list will show:—General Fund, £1,500; Engineering Fund, £1,000; Endowment Fund (Physical Laboratory), £3,000; Jurisprudence Fund, £500. It will thus be seen that he did not exclusively limit his interest to subjects with which he was himself connected. Professor Greenwood states that, from personal intercourse, he knows that Mr. Beyer shared the opinion that the prosperity of such institutions was best secured when all the various branches of liberal and scientific knowledge were pursued in common. In his annual report of June last, speaking of Mr. Beyer, he observes that "his munificent gifts towards the Extension Fund were not more conspicuous than the warm personal interest which he always showed in the growth and prosperity of the College; and by those who enjoyed his friendship his loss will long be severely felt."

For some time before his death, Mr. Beyer's health showed symptoms of failure, which however did not assume a serious character until the early part of 1876. It was then found that he was suffering from great prostration of the nervous system, arising, as is now frequently the case, from too close an application to business, and which would probably have disappeared if he could have yielded to the wishes of his medical advisers, and rested from his labours for a time. Like too many of the members of the profession, he did not find it an easy matter to follow this advice, and he gradually became worse till the time of his death. He was an earnest inquirer after truth, both in science and in religion. He was not unfamiliar with some of the most important aspects of modern religious contoversy; but he lived and died a sincere and enlightened Christian, reposing with child-like confidence upon the merits of his Saviour.

Mr. Beyer became a Member of this Institution on the 7th of March, 1854. He was one of the founders of the Institution of Mechanical Engineers, one of the Governors of Owens College, Manchester, and of the Manchester Grammar School, and a member of several scientific and charitable institutions, and shortly before his death was appointed a magistrate.

This brief sketch of Charles Frederick Beyer will have gained its end, if it serves to keep alive the memory of a man of singular purity and simplicity of character; whose history shows what great results may be achieved under circumstances the most unpromising, when great parts are united to untiring industry, and are directed by high principles and noble and unselfish aims.

MR. RICHARD SMITH CLAYTON, son of Mr. Thomas Clayton, woolstapler, of Bradford, Yorkshire, was born on the 14th of September, 1838. He was educated at the Priory, South Lincolnshire, and at Rugby School. In 1855 he was articled to Mr. (now Sir John) Hawkshaw, Past-President Inst. C.E., with whom he remained four years, during part of which time he was employed on the works of the Holyhead Breakwater. From 1860 to 1867 he was engaged under Mr. John Fraser, M. Inst. C.E., in the construction of railways in the West Riding of Yorkshire, and as Resident Engineer on the West Riding and Grimsby railway (Wakefield to Doncaster). During the latter part of 1867 and the beginning of 1868 he represented the late Mr. Seymour Clarke on the "Railways (Ireland) Commission." In 1869 and 1870 he was engaged in Hungary, under Messrs. Waring Brothers, and afterwards went to Buenos Ayres for that firm, returning in 1871. From this time to June 1876 he was connected with Mr. Fraser in surveys for and in the construction of the Newark and Melton railways (now Great Northern and London and North-Western joint lines), and assisted that gentleman on the surveys of the railways from Melton to Leicester, and other lines in that district. In 1876, the state of his health necessitating his abstention from business, he was recommended by his medical advisers to go abroad. In June he went to North America, where he died on the 5th of July.

He was elected a Member of the Institution of Civil Engineers on the 7th of April 1868.

MR. ROBERT MILLIGAN was born in the year 1827 at Castle Douglas, Kirkcudbrightshire, and was educated at the Academy of that town. He served a regular pupilage to Mr. John A. Brine, C.E., at Birkenhead, and was afterwards engaged for a year in laying out highways in Scotland. In 1851 he was appointed Second Engineer to the projected gasworks at Rio de Janeiro, and in connection with that enterprise prepared the surveys and sections of the city. On their completion Mr. Milligan was employed by H.E. the "Commendador" Ireneo Evangelista da Souza (now Visconde de Mauá) to survey and lay out the Mauá railway (the first constructed in South America), through a most insalubrious district lying between the north end of the Bay of Rio de Janeiro and the base of the great "Serra" of Petropolis. About the end of 1852 Mr. Milligan was sent by the Visconde de Mauá to examine the province of San Paulo as to the feasibility of connecting the great coffee-producing districts of the interior of the province of San Paulo by railway communication with the port of Santos, when he laid out a line from the top of the Serra do Mar to Jundiahy, which scarcely differed from that ultimately adopted when the railway was constructed. On his return to Rio in the following year Mr. Milligan was appointed Chief Engineer and Traffic Manager of the Mauá railway, then opened for public traffic, and to the steam ferries connecting it with the City of Rio, which position he ably filled until 1868, when, after a most successful administration, he was obliged to return home in consequence of failing health. His services were early recognised by the Emperor of Brazil, at whose hands he received the decoration of the Imperial order of the Rose.

Mr. Milligan was elected a Member on the 4th of March, 1862, and he died on the 6th of July, 1876.

MR. ROBERT AYTOUN, the youngest son of Major-General Roger Aytoun, of Inchdairnie, Fifeshire, was born in Edinburgh in the year 1799. He was educated in Scotland, and was for four years at the University of Edinburgh, where he chiefly devoted himself to the physical sciences, mathematics, chemistry, and natural philosophy, in which he acquired great proficiency. After the completion of his education he passed as a Writer to the Signet, and entered into business as a member of the firm of Aytoun and Greig. Among their clients was his eldest brother, who possessed the family estates, through part of which runs the river Leven on its outflow from the lake. Mr. Aytoun's attention was thus directed to the flow of the river, and he was the first to suggest an improvement, which was carried out by Dr. Coventry under an Act of Parliament called "The Leven Improvements." This operation was a great success, and is described in the "Edinburgh Courant" of January 1st, 1831. The chief merit of this work was conceded to him by all parties acquainted with the circumstances. From this period Mr. Aytoun was regarded as a man who had a natural turn for physical science, to which he afterwards devoted constant attention. He became a member of the Royal Scottish Society of Arts, and, on the 11th of June, 1839, an Associate of this Institution. No discovery or invention in physical science which came under his notice escaped his serious attention, and this was especially the case after he retired from the active practice of his profession as a Writer to the Signet, when for some years he undertook the superintendence of the mining operations on a property belonging to himself and other members of the family, and carried it on successfully till 1872.

Mr. Aytoun was a constant attendant at the meetings of the Society of Arts in Edinburgh, and read many Papers before that body. In 1856 he was presented with the silver medal of the Society for an "Improved Assay Balance," and again in 1860 he received their silver medal, with a handsome timepiece, for the invention of a disengaging catch for preventing accidents to miners' cages in cases of overwinding. He also invented a safety cage for mines, and exhibited it in operation at the International Exhibition of 1862, when it obtained honourable mention. Amongst other Papers read by him before the Society was one in 1862 on a means for supplying unlimited brake-power to trains by providing a mid-rail of wood, to be grasped by strong springs attached to the brake-vans and tender. The committee appointed to consider this plan reported that it was perfectly efficient, but not likely to be adopted on account of the expense. This mode of brakeing trains has since been applied independently in descending the steep gradients of the Mont Cenis Upper Railway with complete success. The last Papers contributed by Mr. Aytoun to the Scottish Society of Arts were on a "Proposed New System of Working Railways by Compressed Air," and "A Mode of Raising Water from Mines by Compressed Air."

In July 1874 a letter from him appeared in the journal "Iron," entitled "New Theory of Comets," which drew an answer from Mr. George P. Bidder. This was his last effort in his favourite direction, as within a few days of the publication of this letter he was seized with an attack of bronchitis, which carried him off after some weeks' illness on the 9th of September. For many years before his death he had been the senior member of the Royal Scottish Society of Arts.

MR. WILLIAM BARBER was born in the Parish of St. James, Piccadilly, on the 15th of December, 1817. He began his engineering career as a pupil with the late Mr. Francis Bramah, M. Inst. C.E., and subsequently with Messrs. Bramah and Robinson, of Pimlico, in whose factory he remained for five years from October 1833. He was afterwards engaged by the late Mr. I. K. Brunel, V.-P. Inst. C.E., as assistant on the Bristol and Exeter railway, under Mr. W. M. Peniston, M. Inst. C.E., the Resident Engineer, with whom he remained at Uphill, Somerset, until June 1840, when he was moved to Bridgewater. Here he had the chief direction of the creosoting of the permanent way timbers, bridges, &c., and measured up the permanent way and timber work between Bridgewater and Taunton, including the sidings at the station at the latter place. In December 1844 Mr. Barber, still under the auspices of Mr. Brunel, proceeded to Plymouth to occupy a similar position in the service of the South Devon Railway Company, and on the completion of the work in March 1847 he came to London as one of the secretaries to Mr. Brunel, by whom he was held in great esteem, remaining at the office in Duke Street until the death of Mr. Brunel in 1859. Then, for a few months, he was auditor of the engineering accounts of Mr. R. P. Brereton, M. Inst. C.E., Mr. Brunel's successor, and in September 1860 became secretary to Mr. (now Sir John) Coode, M. Inst. C.E. In 1875 Mr. Barber acquired considerable property, which enabled him to retire from the profession.

Mr. Barber was distinguished for his accuracy and power of continuous work; and he manifested a special aptitude for accounts. His admirable business habits and capacity were not confined to earning a livelihood for himself, but were often placed at the disposal of others, and in one instance he gratuitously managed the estate of the orphans of an early friend during their long minority, a task which involved the sacrifice of much of his spare time through several years.

His connection with the Institution would have dated from the 26th of January, 1841, when he was passed by the Council as a Graduate, but ill-health induced him to withdraw his application for admission, which remained in abeyance until 1871, when he again came forward, and was elected an Associate on the 7th of March in that year. He died from heart disease on the 3rd of November, 1876.

MR. BENJAMIN BURLEIGH was born at Oxford on the 24th of May, 1820. Owing to the death of his father he entered upon the active duties of life at the early age of fifteen, and before he was nineteen had executed in a satisfactory manner many large parish surveys. He was afterwards engaged by Colonel Landmann and the late Mr. John Braithwaite, M. Inst. C.E., in making designs and drawings for bridges and other works on the Eastern Counties railway. In the year 1845 Mr. Burleigh became chief of a large surveying party under Mr. Gregory, Past-President Inst. C.E., in preparing surveys for a proposed line. He was then employed on the East Lincolnshire railway, under Mr. James Hodges, and, on the completion of those works in 1849, on the construction of the Great Northern railway, as the Resident

Engineer on the section between London and Peterborough under the late Mr. Cubitt, Vice-President Inst. C.E. He designed and carried out many important works on the line, including the viaduct at Peterborough, and the aqueduct over the Regent's Canal. On the termination of this engagement Mr. Burleigh took offices in Westminster, where he practised as an Engineer and worked out patents, amongst which may be mentioned "Switches and Crossings," "Railway Fastenings," "Concrete Blocks," weighing 300 tons each, for harbour works, "Rotary Lever," "Solidified Charcoal Blocks for Filters"—specimens of which blocks he had the honour of submitting to H.R.H. the late Prince Consort.

Mr. Burleigh originated the idea of the "Working Man's Home," on the system of a joint-stock association, and had a prospectus printed, dated the 13th of May, 1863; but, owing to not having sufficient interest, he was unable to carry out this idea. He also proposed the construction of an underground railway from King's Cross down the Goswell Road and Aldersgate Street to the Mansion House, and in August 1853 prepared drawings for the same; but the scheme was looked upon as visionary, and he was unable to carry it out. In 1862 and 1863 he designed and superintended, as Chief Engineer, the construction of the Bristol Port railway from Clifton to Avonmouth, after which he superintended, for Sir John Hawkshaw (Past-President) and Messrs. G. R. Stephenson (President) and Burke, the construction of the East London railway from New Cross and the Kent Road to Wapping through the Thames Tunnel, when he designed and carried out many important works. For a short time he was connected with the Indian State railways, under General Strachey, and in the year 1873 was appointed Architect to the North-Eastern Railway Company, which post he held up to the time of his death, on the 25th of April, 1876.

Mr. Burleigh was elected an Associate on the 1st of February, 1853. He was also a Member of the Council of the Inventors' Institute, and one of the scientific referees of the Patent-rights Association.

LIEUTENANT-COLONEL CLEMENT JOHN MEAD, son of the late John Clement Mead, of Keppel Street, Russell Square, architect of the first General Post Office, &c., was born on the 19th of April, 1832. After passing through Addiscombe in 1849-50, and qualifying for the Bengal Artillery, he joined his regiment at Dum-

Dum in 1851, and on the breaking out of the Burmese War, for which he afterwards received the medal, was ordered, in 1852, to Akyab and Kyouk Phoo. At this time he was selected, being then only twenty years of age, to survey and report on the Aeng Pass, by which it was intended to send troops to Burmah, and in the following year he was intrusted with the construction of the road still known as "Mead's Road." The region thus traversed was an unknown track of hill-country, covered with dense forest jungle, and sparsely inhabited by wild and fierce tribes, in a state of chronic war amongst themselves. On one occasion, when the small survey party entered a village at the end of a tiring day's march, the head-man, or chief of the local tribe, gravely inquired if Lieutenant Mead would object to his guides being executed, as the local tribe was at deadly feud with the newcomers! As may be imagined, it was not always an easy task to maintain peace and order amongst such a barbarous and utterly lawless population. Indeed dangers and hardships, for want of the ordinary necessaries of life, food and shelter, in a most trying climate to European constitutions, were encountered, which could only have been successfully dealt with by such a firm yet always kindly and even-tempered nature. In these early days he won the respect and affectionate confidence of the natives, and never, to the last, ceased to arouse and influence their worthier feelings.

For his services at this time Lieutenant Mead was twice thanked in Public Orders by Lord Dalhousie. But clearing jungle in India is well known to be a most deadly employment: his subordinates on the work one after the other died at their post, or were invalided; and he was at last, after trying a short, ineffectual leave to the Straits for the restoration of his health, compelled to apply for sick-certificate and permission to return to Europe. On passing through Calcutta, however, at the close of 1857, his services were temporarily requested by the military authorities, and he was placed in command of a battery, hastily raised and manned by sailors of the Indian navy, stationed at Barrackpore for the protection of the inhabitants of Calcutta, in the event of disturbances, anticipated at that moment with keen anxiety. Lieutenant Mead's health was, however, so shaken that he was, in truth, utterly unfit for active service, and as soon as it was possible to release him from his post, the doctors insisted on his return to England as a measure of urgent necessity.

He arrived in England in the spring of 1858, and, after a short rest, adopted the unusual course of entering an engineering establishment, then largely engaged on iron girders, bridges, and general constructive work, and here he made himself practically acquainted with the details of such work, which he found later of the utmost value, since it enabled him to show with his own hands to native workmen how "riveting up" and similar work should be done.

At the beginning of 1859 Captain Mead was again in India, when he was employed in the Public Works Department, first at Patna, then at Sherghotty and Nagpore, and was mainly instrumental in constructing what is known as the "Nizam's Railway" at Hyderabad, and furthering the objects of the Berar Exhibition as regarded the machinery department. The last four years of his life were spent on the survey, laying out and arranging, as Engineer-in-Chief, for the construction of the "Sindia Railway" from Agra to Gwalior, which, among other works, included a viaduct of fourteen spans of 200 feet each, on piers about 115 feet high, to cross the river Chumbal. The plans and estimates for these works have been accepted by Government, and the contract taken.

He left Agra, at the beginning of July 1876, on three months' privilege leave—perhaps his first real holiday. While crossing between Calais and Dover, during the night, he is supposed to have caught the cold which led to his illness and unexpected death on the 27th of August, at the early age of forty-four. He was gazetted Lieutenant-Colonel only a day or two before he died, and leaves a widow and seven children.

Colonel Mead was elected an Associate of the Institution on the 1st of February, 1859.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The New Portage Bridge. By GEORGE S. MORISON.

(Transactions of the American Society of Civil Engineers, vol. v., p. 1.)

THE timber viaduct, 850 feet in length and 234 feet in height, built in 50-foot spans, over the Genesee river at Portage, on the Buffalo division of the Erie railway, was destroyed by fire on the 6th of May, 1875. There being another line over which the traffic could be accommodated, it was considered inexpedient to erect a temporary bridge, and it was decided to rebuild the structure in iron. In repairing the masonry footings, for the support of the iron columns of the piers, use was made of Coignet beton for the covering of the upper parts, and of those exposed to the destructive action of frost and water. On the 13th of June the first column was raised, on the 29th of July all the ironwork was in position, and on the 31st of July the bridge was tested. The railway on the two sides of the Portage bridge consists, for 20 and 30 miles respectively, of a single line of rails, but, as the doubling of the line had for some time been contemplated, the piers were constructed of sufficient strength for a double line, while the main girders, placed 20 feet apart from centre to centre, can be strengthened for a double load by placing similar girders alongside them. The bridge stands at the foot of a gradient of 1 in 100, extending for about 1½ mile, but, as it may be desired at some future time to lower this gradient by raising the bridge, provision has been made in the heads of the columns to add 20 feet to the piers. The iron viaduct consists of ten spans of 50 feet each, two of 100 feet, and one of 118 feet, one of 50 feet being placed between each of the longer spans. There are six piers measuring 50 feet in the direction of the length of the bridge by 20 feet at the top. Each pier consists of four corner columns of wrought iron; these are parallel in side elevation, but are inclined to each other with a batter of 1 in 8 in the transverse section of the bridge. The two loftiest piers are 203 feet 8 inches in height from the masonry to the rail, and, battering from the top at 1 in 8, are 69 feet 8 inches in width at the bottom between the centres of the columns. The columns are in lengths of 25 feet, rectangular in section, and are built of boiler-plate on three sides, with angle-irons at the corners, 4 inches by 4 inches by ½ inch, the thinnest plates employed being ½ inch thick. On the fourth side of the columns latticing is substituted for boiler-plate, thus leaving the interior open for painting. The columns are stiffened by horizontal struts, 2 feet deep by 1 foot wide, of the form of a light lattice girder, 50 feet in length in side elevation, and varying from 20 feet to 64 feet in length in the transverse section of the bridge, with diagonal tie-rods 1¼ inch in diameter attached to the same pins in the columns. The main girders rest at each end on a single column, and the distance across the top of each pier between the corner columns is crossed by a girder of 50 feet span. The main girders were designed for a load of 3,000 lbs. per lineal foot, with a maximum tensile stress of 10,000 lbs. per square inch. The piers are built to carry a load of 5,400 lbs. per lineal foot in addition to the estimated weight of the superstructure for the double line, as well as a wind pressure of 30 lbs. per square foot on the entire surface of the structure, and on a train of cars on the top, and one of 50 lbs. per square foot on the structure alone. The maximum compression allowed in the columns is 6,600 lbs. per square inch, and the maximum tension in the diagonals 15,000 lbs. per square inch. The stresses are estimated on three suppositions—1st. A load of 5,400 lbs. per lineal foot, besides the weight of the superstructure for a double line, with no wind pressure; 2ndly. A load of 2,800 lbs. per lineal foot (a double line of loaded cars), and a wind pressure of 30 lbs. per square foot at right angles to the bridge; 3rdly. A wind pressure of 50 lbs. per square foot alone, with a single-line superstructure: this latter condition approaches most nearly to the limit of stability of the bridge, but in this case the columns are nowhere in tension. The load on a single column of one of the piers amounts to 357,000 lbs., which, distributed over a stone pedestal 4 feet square, is equal to 155 lbs. per square inch, the footings being nowhere less than 10 feet in thickness. Assuming an equal distribution of the load in all directions, the pressure per square inch on 10 feet square of the foundations amounts to 24·8 lbs. The weight of ironwork in the bridge is as follows:—

	lbs.	lbs.
Pier, 46 feet in height	43,860	
„ 60 „ „	57,867	
„ 165 „ „	185,048	
„ 203 feet 8 inches in height . .	277,890	
„ 203 „ 8 „ „ . .	284,486	
„ 60 „ in height	48,399	
Total weight of piers		897,550
Ten spans, each 50 feet.	197,420	
Two „ „ 100 „	128,910	
One span, 118 „	86,120	
Total weight of superstructure .		412,450
Total		1,310,000

	$
The total cost of the ironwork, including erection, was	87,973
The cost of the floor, handrail, and footways was .	6,200
Painting (one coat)	1,200
Total	95,373

The original timber structure was begun on the 1st of July, 1851, and completed on the 14th of August, 1852; it contained 1,602,000 feet (B.M.) of timber, and 108,862 lbs. of iron; the foundations contained 9,200 yards of masonry, and the total cost was about 140,000 dollars.

A. T. A.

Bridge over the Elbe at Dömitz. By E. Häseler.

(Zeitschrift des Architekten- und Ingenieur-Vereins, Hannover, vol. xxii., p. 239.)

This is a wrought-iron bridge built to carry the Wittenberge-Lüneburg railway (double line) over the Elbe, and consists, commencing from the right bank of the river, of four spans of 105 feet, two of 44 feet, four of 213 feet, and sixteen of 105 feet, all of which (except the two spans of 44 feet, belonging to a swing bridge) are crossed by girders constructed on Schwedler's system.

The 105-foot and 213-foot spans differ in construction in this respect only, that the former are furnished with a single, the latter with a double diagonal system; the details of the latter only form the subject of this Paper.

The main girders are 27·2 feet from centre to centre, and have a clear span of 213·25 feet, and an effective span of 222·41 feet. To the verticals of the main girders, cross girders are attached, which support the four rail girders, each pair being 6·17 feet apart, with a central interval of 5·15 feet. Over these are wooden sleepers 8·27 inches by 10·24 inches in section, which carry the rails. They are laid at intervals of 3·08 feet, and are notched to a depth of $\frac{3}{4}$ inch into the rail girders, longitudinal motion being prevented by angle irons, $2\frac{9}{16}$ inches by $2\frac{9}{16}$ inches by $\frac{3}{8}$ inch, fastened to each pair of the latter.

The bottom boom is divided into nineteen bays, each 12·35 feet wide, with the exception of the second and third from each end, which are only 9·25 feet. The cross section of this boom consists of two vertical side plates, 18·54 inches high and the same distance apart, which, up to the third joint, are stiffened by four angle irons outside each, and beyond this joint by two more angle irons placed inside; the interval between the fifth joint from either end having also flat plates covering the lower flanges. The top boom is similarly constructed, but is in addition provided with a top plate, and stiffened by four angle irons outside each side plate, and two inside at each joint, in order to transfer the pressure from the joint plates of the diagonals direct to the top plate of the boom.

A peculiarity in the design is that the top boom, for a length of three bays on each side of the central bay, is straight, instead of being curved as usual, and, further, there is no diagonal connecting the top of the first with the foot of the second vertical; the system is consequently imperfect, *i.e.*, wanting in rigidity, but this defect is, to some extent, compensated by extra stiffness at the joints.

Riveting and Jointing of the Booms.—This is effected by 1-inch rivets of 3·15 inches pitch at the joints and 6·3 inches pitch between them. The top plates of the upper boom have cover plates on one side only at the joints; the angle irons are connected by means of angle covers, and the side plates of both booms have cover plates on both sides of the joint, which are cranked over the angle irons.

The requisite number of rivets for the transfer of the forces from the upper boom to the lower is computed from the net cross section of the eight angle irons of the lower boom, that is, is equal to $\frac{200}{5 \cdot 3}$ square centimètres = $\frac{31}{\cdot 82}$ square inches = 37·7, say forty rivets. As the vertical force of the upper boom is transferred direct to its support, no rivets are here required.

Diagonals and Verticals.—The former are placed double at all the joints, and consist of flat bars, $\frac{1}{2}$ inch thick, which are fastened to the joint plates of the booms by 1-inch rivets. At the crossing places of the diagonals and verticals they are connected by screw bolts, washers being placed between them in order to subdue the rattling caused by the passage of trains. The verticals are built like plate girders, and are attached to the booms by $\frac{3}{4}$-inch rivets. In the case of the two first, where tension only has to be taken into account, the web is completed by angle irons $2\frac{9}{16}$ inches by $2\frac{9}{16}$ inches by $\frac{3}{8}$ inch; but in all the others the angle irons measure $2\frac{9}{16}$ inches by $4\frac{1}{8}$ inches by $\frac{3}{8}$ inch.

Upper and Lower Horizontal Bracing.—The former begins at No. 2 joint of the upper boom, and consists of a fourfold diagonal system, of which the struts are formed like plate girders, about $\frac{3}{8}$ inch thick, and stiffened by four angle irons, $2\frac{9}{16}$ by $2\frac{9}{16}$ inches by $\frac{3}{8}$ inch.

The diagonals throughout are $\frac{3}{8}$ inch thick and 3 inches broad. The bending of the struts is prevented by fastening them at their centre to the diagonals, and, in addition, by riveting angle irons under them, at intervals of 6·17 feet from the centre. The ends are also supported and attached to the verticals by brackets placed at an angle of 45° and $2\frac{1}{2}$ feet from the verticals.

The lower horizontal bracing consists also of a fourfold diagonal system. The plane of it is at the height of the centre of the lower boom, and passes through the web of the cross girders. To prevent cutting out the latter at the crossing places, the diagonals are here interrupted, and are secured to the web on both sides by double joint plates. The diagonals are from 3 to 6 inches broad and $\frac{1}{2}$ inch thick; and for the upper bracing $\frac{3}{4}$-inch and for the lower 1-inch rivets are used. The main girders rest at one end on a movable and at the other on a fixed cast-iron saddle.

In the first case the upper boom rests directly on the top of the saddle, and is fastened to it by bolts 1 inch in diameter. To correct any unevenness in the bottom flange of the boom, a sheet of lead, about $\frac{1}{8}$ inch thick, is placed on the top of the saddle. The lower part of the saddle rests on eleven rockers, 3 inches wide, $8\frac{1}{4}$ inches high, and 31 inches long. These lie on a bed plate, 3·44 feet square and $2\frac{1}{2}$ inches deep, which is laid in cement on a granite block 5 feet square and 1·7 foot deep.

Side oscillations of the rockers are prevented by turning up the edges of the bed plate and turning down the edges of the lower face of the saddle, and the surfaces in contact with the rockers are accurately planed. In the case of the fixed support, in place of the rockers, a strong cast-iron frame receives the saddle, and the edges of the latter are turned down so as to prevent any motion of the parts. This frame is also bedded in cement on a granite block 5 feet square and 1·7 foot deep.

Cross Girders and Rail Girders.—The cross girders have an I section, and are stiffened at their ends by means of triangular plates attached by double angle irons to the verticals. The rail girders correspond to the length of the bays, and are 12·35 feet and 9·25 feet long, with depth of web plate 20 inches and 15 inches respectively and $\frac{3}{8}$ inch thick, and the angle irons are $2\frac{9}{16}$ by $2\frac{9}{16}$ inches by $\frac{3}{8}$ inch.

The end rail girders rest in shoes on the piers at one end, and are riveted to the cross girder at No. 1 joint on the other. Since these partake of the movements of the main girders at the moveable support ends, the joint plates which connect them together over the pier are furnished with slots. Each pair of end rail girders is connected at the shoe supports by means of a plate girder, and the ends of two contiguous rail girders resting on the piers are similarly joined together. The expansion contrivance for the rails is mounted on a bed plate, and is constructed in the usual way. Outside the bridge, and facing up stream, is a footway about 4 feet wide, supported on cantilevers, and covered with strong 2-inch planking.

The following Plates accompany the Report, viz.:—

1. Longitudinal section and plan of girder for one-half span.
2. Cross section of girder at middle of a span, and details of the horizontal bracing.
3. Details of jointing and riveting.
4. Details of rail girders on the piers, and details of the masonry on the top of the piers.

W. H. E.

Iron Railway Bridge over the Inn. By H. GERBER.

(Zeitschrift des Bayerischen Architecten- und Ingenieur-Vereins, vol. viii., p. 1.)

The Rosenheim-Mühldorf portion of the Bavarian State Railway crosses the river Inn twice; at Königswart at a height of 157 feet, and at Jettenbach at 65 feet above low water. The bridge at Königswart consists of three spans of 226 feet from centre to centre of piers, and two small ones of 87 feet and 67 feet. The girders of the eastern and western large spans were put in place by the erection of wood scaffolding 20 feet square and 121 feet high, standing in the centre of the spans, and by the help of temporary iron girders 87½ feet long. It was proposed to put the girders of the central span in position in the same way, and the scaffolding for doing so had been partly erected in June 1875, when it was carried away by a sudden freshet. It was impossible to restore the scaffolding before the winter, and it was therefore decided at once to adopt another course of construction.

In 1866 the Author had been engaged on the erection of a bridge without scaffolding over a ravine near Hohenschwangau, 115 feet wide and 321 feet deep. It was completed in a short time by fastening anchorages to the rock on each side, and adding the several bays of the bridge to these until they joined in the middle.

At Königswart the girders of the finished spans on either side did service as anchorages for the erection of a temporary bridge across the central span. The temporary bridge hung suspended from frames 16½ feet high, fixed on the top of the finished stone piers until the two ends could be joined, and to do this accurately these frames could be moved horizontally in the direction of the bridge by screws working against their foot, and the ends of the bridge could be raised or lowered by universal joints and union screws at their point of anchorage. The force brought to bear on the high stone piers of 52 yards exerted thus a vertical action only, and this to the extent of 51 tons on each, whilst the strain on each anchor came to 35 tons. After the completion of the temporary bridge it was lowered 2 yards, and the permanent bridge could immediately be taken in hand.

The erection of the temporary bridge took about nine weeks, including a fortnight's stoppage on account of an accident to the erecting crabs. The permanent bridge span was begun on December 8th, and finished on January 6th, 1876. The weight of iron of the temporary bridge (without anchorage), having a span of 218 feet, was 84 tons. A photograph of the work is appended.

E. E. S.

The Belle Alliance Bridge in Berlin.

(Deutsche Bauzeitung, vol. x., p. 451.)

This bridge, which crosses the Landwehr Canal in a line with the Friedrichsstrasse, was finished in October 1876, having been a year and a half in building. In architectural appearance and in size it is decidedly one of the finest bridges in Berlin. Its advantageous position, close to the Belle Alliance square, and the great traffic which it has to accommodate (the bridge is crossed daily by 1,000 tram-cars, and 8,000 other vehicles), rendered it necessary that the scanty proportions which distinguish most of the Berlin bridges should, in this case, be considerably exceeded.

The new bridge crosses the Landwehr Canal with an elliptical arch of 61 feet 8 inches span. The height of the crown of the arch above the springing is 13 feet 9 inches. The radius of the arch is 55 feet 9 inches, and the clear height above high-water mark 10 feet 4 inches. The arch is three bricks, 2·65 feet, thick at the crown, the total thickness of the work being 3·28 feet. The strain on the brickwork is calculated at 142 lbs. on the square inch. The line of strain passes through the crown of the arch at one-third of its thickness from the summit. The bridge is crossed by six flat gas-pipes, each 4 feet broad, and by two water-pipes. The available space being so limited, it is necessary that these should penetrate into the crown of the arch, so that at the weakest parts it is reduced to 2 feet 1 inch by 1 foot 4 inches thick. To compensate for this, ribs three bricks and a half thick are introduced close to the part which has been cut away.

The roadway of the bridge is of concrete, covered with a layer of compressed asphalt 1½ inch thick; the footpaths on either side are paved with granite. The total breadth is 110 feet 4 inches, of which the roadway occupies 62 feet 4 inches, and each footpath 24 feet. A double line of tram-rails is laid in cast-iron boxes. As the arch is carried down below low-water mark, and the extrados is covered with a layer of concrete, going down to a considerable depth, the slight depth of the foundations (about 10 feet below low-water mark) renders actual counterforts unnecessary, and the arch springs from a foundation of concrete 4 feet thick. The arch and wing walls are faced with sandstone, and the balustrade is of granite from the Fichtelgebirge. The building of this bridge rendered it necessary to raise the approaches considerably, to build retaining walls, and to repave some 194,000 square feet of road. The cost of the whole work exceeded £25,000, and of this sum about £5,000 were devoted to the embellishment of the bridge.

The artistic part of the work was designed by Herr Strack, and the technical part by Herr E. Dietrich.

W. W. W.

On the Modern Tracing of Railways.

By HEINRICH GOLDSTEIN.

(Allgemeine Bauzeitung, vol. xli., pp. 38, 49, 1 Plate.)

The essentials of a good-contoured design having first been enumerated, the Author proceeds to discuss the existing methods for finding heights, none of which, he affirms, satisfies the claims of rapidity, accuracy, and cheapness in an equal degree. The oldest method is that of taking cross sections by means of a level and levelling staves perpendicularly to a rectilineal or polygonal axis lying somewhere about the position of the centre line of the railway to be traced. From this axis the side lengths and horizontal angles, &c., are measured. A second method is by pegging out the contours on the ground, and their subsequent survey from points already fixed. Lastly, a third method is by employing the telemeter in one of its various forms, which from some one station fixes the distances and heights of the points visible therefrom, especially of such as are useful for contouring.

Whichever method, however, be adopted, special advantages are secured by tracing out a polygon before commencing the detail operations, instead of determining one during their progress; or, what is still more awkward, but nevertheless sometimes happens, at their close. The polygon at once fixes an important and costly point, *i.e.*, the breadth of the survey, because no empirical rule, such as from 500 to 650 feet on each side of the line, is of any value, since the height of the railway itself can alone determine it; and this, though not actually fixed, has at all events certain limits, which can be settled beforehand, and thus save unnecessary time, expense, and labour. If the polygon be plotted as a longitudinal section by means of trial levels, a rough approximation is obtained of the height of the railway, and it can be seen at once whether the polygon ought to be moved, and in what direction. An example within the Author's experience is given in illustration.

The suitability of the line having been proved, its length must be accurately measured with rods and spirit-levels, and checked approximately by the telemeter. Every station must be directly levelled, and its co-ordinates with reference to the meridian trigonometically computed for insertion on a plan, after which the plane-table sheets are made out. Great accuracy in this branch of the work is insisted on, or the pegging-out of the line on the ground will not agree with that shown by the plan.

I. HEIGHT-FINDING (KOTIRUNG) BY MEANS OF CROSS SECTIONS.

The oldest method of taking cross sections on the polygon lines, and of interpolating contours between each point, is nearly given up, though useful for certain purposes. Cross discs are employed for setting out the perpendiculars with a maximum difference, in a section of 820 feet length, of 3·15 inches from the true perpendicular—a difference quite unappreciable on the scale used (1 : 2500, or 1 : 5000). In broken ground this method is arduous where the measurement has to be 'stepped,' and where the level has to be constantly set up, but in gently undulating ground these difficulties vanish. The cross-section heights can be graphically plotted for each ground point from the field notes on squared paper, and, when arranged in order, are superior to a contoured plan for the study of the line, especially if the formation-level be shown. This method is besides as cheap and as accurate as any other, and requires no special technical skill in manipulation.

II. Height-finding by means of Pegging out the Contours.

This is done by finding with the level from a known point other points of similar elevation, pegging them out, and then surveying them by the plane-table; but the method is laborious—entailing much personal exertion on the part of the surveyor and his assistants—takes up too much time, and creates confusion; besides, it does not sufficiently characterise the ground, because such features as do not happen to lie on a contour must be fixed by a second method. For the Gothard railway, on which it has chiefly hitherto been put in practice, the plane-table was used with the topographical telemeter (Professor Wild's) for the interpolation of points; but this combination of an accurate method with one less accurate is deprecated by the Author. Its chief disadvantage, however, is the cost, which for an ordinary plane-table sheet of this railway on difficult and hilly ground is £160.

III. Telemeters (Wild's Method).

Telemeters are most employed for measuring heights, the Reichenbach principle being the one in vogue for determining the distance of a station by the projection of the two parallel hairs of the cross hairs on a vertical pole. This idea has originated two methods, which, seemingly different, are yet in reality only a graphic and analytic expression of a common principle. The graphic method (Wild's) is indigenous to Switzerland and South Germany, while the analytic is of French origin, introduced first by Porro, but not practised extensively until used by Moinot in his designs for the French Orleans railway.

The Author first examines the principle common to both methods, and then explains their practice. Supposing D_o = the distance of the pole from the object-glass of the telescope, and D = its distance from the centre of the instrument, then, if the object-glass stand at its half focal distance ($\frac{1}{2} f$) from this centre,

$$D = D_o + \tfrac{1}{2} f;$$

if, further, a = the limit of the projection of the two parallel cross hairs (upper and lower) upon the pole,

$$D_o = f + C_a,$$

where C is a constant to be specially fixed for each telescope, and consequently

$$D = \tfrac{3}{2} f + C_a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This formula, however, is not sufficient, since it is rarely possible to see the pole when the telescope is horizontal, and therefore a further analysis of it is made with the telescope tilted, where O being the object-glass, B, C, E, the projections of the three cross hairs upon the pole, a the angle made by the tilted axis with the horizon, and $\frac{\sigma}{2}$ the angle made by the principal rays OB, OE (upper and lower) with the tilted axis,

$$D_h = D_s \cos a = \tfrac{3}{2} f \cos a + C \, . \cos a \, . \, \frac{\overline{BC} \cos\left(a + \frac{\sigma}{2}\right) + \overline{CE} \cos\left(a - \frac{\sigma}{2}\right)}{\cos \frac{\sigma}{2}} \quad . \quad . \quad (2)$$

This equation gives the distance exactly when four elements are determined, viz., $\overline{BC}$, $\overline{CE}$, a, and σ; of these, all but the angle σ are directly observed, and therefore it must somehow be eliminated from the equation. By assuming $\sigma = 0$, this equation may be approximately written thus,

$$D_h = \tfrac{3}{2} f \cos a + C \, . \, \overline{BE} \cos^2 a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The error of this, even in the most unfavourable circumstances, amounts to not more than 0·0117 inch, proving that the angle σ may be neglected. Equation 4 forms the basis of both the analytic method with the theodolite and of the graphic with the plane-table.

In determining differences of height (h) the precaution may be obviated of noting the different course to be adopted when a is an elevation or a depression. The centre cross hair is set so that its reading on the pole (l) is equal to the height of the instrumental axis (i) at the observing point, in which case invariably $h = \tau \, (D_h \text{ tang } a)$; but such a course has disadvantages, because, 1st, the graduation which should be covered on the pole by the centre hair may not always be seen, owing to obstacles in the line of sight, and, 2nd, the accurate setting of the centre cross hair takes up too much time, and, moreover, prevents the lower hair from being set on a round number of the pole—a most desirable step for rapidly determining the pole piece a. In theodolite work, where the angles and pole readings are booked in the field, and the distances and differences in heights afterwards computed in the office, rapidity in the field work is essential, and therefore the lower cross hair should invariably be placed on a round number, but when the plane-table and sight-vane are used, where the whole work must be completed in the field, the centre cross hair should be set upon the pole at the height of the instrumental axis.

FIELD NOTES (CARNET).

First observing that with the plane-table no booking is required, since the calculations are done at once in the field by either computing slides, diagrams, or tables, and the point is plotted in its right place on the sheet, the Author proceeds by an illustration to exemplify his system of booking in theodolite surveys, remarking that it differs from Moinot's form in not having a separate column for the number of the station, which he considers superfluous. Moinot divides the field work amongst four people; No. 1 is at the instrument, and only reads; No. 2 books No. 1's readings; No. 3 directs the pole-bearers, and No. 4 sketches into a book, in their proper positions (so far as he can do so in the time) and numbers, the stations which No. 1 has read off, and No. 2 has booked. This plan insures great accuracy and rapidity, since more than 1,000 points can easily be fixed in one day. It is unnecessary, however, for obtaining good results; 1st, because it is simply mechanical, and, from its nature, irksome for any lengthened period; 2ndly, because in bad weather, at the setting-up of the instrument, or at the search for subsidiary stations, the whole "Brigade" (as Moinot terms them) are idle together; also because any error made by one throws the other three out of work.

Porro-Moinot's method can be simplified thus, and gives far more accurate results. Supposing the instrument to be at station V, the pole-bearer will walk in a straight line V*b*, directing himself by two fixed poles; if V*a*, V*b* (two straight lines) be chosen so that they contain, with the line joining stations IV, V, angles which can be quickly represented geometrically (such as 30°, 45°, 60°, 90°, &c.), the reading and booking of the horizontal angle for every point in those directions will be unnecessary, as well as the plotting them afterwards with the protractor (the greatest source of errors in the telemetric method), while on the rapidly and accurately constructed lines V*a*, V*b*, V*c*, &c., every point will be plotted by its distance. And, lastly, since each point of a straight line lies in turn always farther from the station, a small but valuable check is obtained by graphic plotting. This method is nearly as valuable as Moinot's required sketch of the numbered and observed points, while it is cheaper, more rapid, and less liable to error.

THEODOLITES FOR RAILWAY TRACING.

These differ from the ordinary ones in having two extra attachments, viz., a box compass, and a telescope with a field lens, which has for its aim the doing away with the first term in equation 4, $\frac{3}{2} f \cos a$. Both additions are absolutely unimportant, as, 1st, the box compass only makes the instrument heavier, and the bearing of a point on the horizontal circle of the instrument can always be read; and, 2ndly, the field lens, although of assistance, can easily be dispensed with, as the addition of $(\frac{3}{2} f)$ the $1\frac{1}{2}$ focal distance to the pole reading $\overline{BE}$ can easily be done mentally, or by the computing slide, as will be explained presently. For these reasons the use of a more complicated instrument can be avoided.

Professor Jordan has proposed a simple graphic diagram for determining the distance of a point ($C_a \cos^2 a$); but as a second diagram must be made to find τ in order to obtain the difference in height, this method cannot be long-lived, as simultaneous work with two diagrams is not feasible. The best way to obtain these two calculations is by the use of a computing scale on which the logarithms of each term are graphically represented, when by sliding a movable portion their addition and subtraction are accomplished. Two of these scales are in use: the first is made of bright silver, and perfected by Kern, who specially arranged to make the constant (C) of all his telemeters = 100, and then obtained these simple formulæ for finding distances and heights, viz.:—

$$\log D_h = \log (100\, a + \tfrac{3}{2} f) + \log \cos^2 a \quad . \quad . \quad . \quad . \quad (11)$$

$$\log \tau = \log (100\, a + \tfrac{3}{2} f) + \log \frac{\sin 2\, a}{2} \quad . \quad . \quad . \quad (12)$$

Now $\log \cos^2 a$ and $\log \frac{\sin 2\, a}{2}$ being negative numbers, his computing scale made the two subtractions by the movements of two sliding pieces respectively along it; while upon the scale itself the logarithms of the natural numbers from 1 to 100 are shown.

The merits of this scale are: its facility in use over a diagram (like Jordan's), and its handy form. Its disadvantages are considerable: 1st, on account of the small unit adopted for its divisions, it is difficult and wearisome to read; 2ndly, for the same reason, it is inaccurate; and 3rdly, its greatest fault, two motions must be made for every station, viz., one slide movement for determing D_h, and another for τ. These, however, are obviated by the improved computing scale of Kraft, which with one movement gives both these values. Kraft's scale is made of wood, with the divisions shown on white paper pasted upon it,—it is therefore easier and pleasanter to read,—is longer than Wild's, and one-fourth the price, while its one sliding-piece moves in a groove

With both, however, it is necessary to add to the piece read on the pole *a* the term $\frac{3}{2}\frac{f}{C}$, because it is required for setting the * point of the sliding-piece. Although this is not difficult, it can easily be avoided by showing on the scale, instead of the logarithms of the natural numbers of 1 to 100, those of these numbers each increased by $\frac{3}{2}\frac{f}{C}$, when, by setting the lower * point of the sliding-piece upon the quantity *a*, the constant addition of the $\frac{3}{2}\frac{f}{C}$ is got rid of.

The essay ends with a reference to the protractors in use for laying down on paper the horizontal angles read by the Porro-Moinot method. These are characterised as faulty, notwithstanding that the two sets of graduations marked thereon are made in two different colours, viz., black and red. Frequent as well as great errors are introduced by the protractor, and the Author therefore advocates in its place the use of his simplification of the Porro-Moinot method.

To sum up: if there be no lack of time for the preparatory field work, and if a continuance of fine weather may be hoped for, then Wild's method with the plane-table, provided good draftsmen are at hand, is the best at present in use. If, however, a large and not so well-instructed staff be provided, and if only a limited time can be devoted to field work proper, and there be a prospect of bad weather, then the method with the theodolite is recommended.

E. H. C.

On the Life of Rails, especially of Bessemer Steel Rails.

By H. Funk.

(Organ der Fortschritte des Eisenbahnwesens, vol. xiii., p. 177.)

At a meeting of the Engineers of the Austro-German Railway Institute in 1873, the average life of rails on twenty-three different lines, with less traffic and lighter engines than at present, was found to be sixteen years. The length of roads under the above direction was

In Germany	43,798,764	lineal yards.
„ Austria	22,658,711	„
Or a total of	66,457,475	„

This length multiplied by 2 for both rails, and taking an average weight of 64½ lbs. per yard, with an average life of sixteen years, gives an annual renewal of 243,000 tons. As the mean difference of price between new and old rails was then £3 10*s*., there resulted a yearly loss of £850,500. Allowing the time to be insufficient for reliable data, the Author gives the following tabular result of observations on the Köln-Minden railway with four different kinds of rails, laid on a trial length at both ends of the station at Oberhausen, from the autumn of 1864 to the 1st of October, 1875, when an accurate revision was made:—

No.	Description of Rails.	Name of Works.	Laid End of 1864.	Remaining Oct. 1st, 1875.	Number of Rails changed.	Percentage of Rails changed.
1	Fine-grained iron .	Froisdorf .	150	35	115	76·7
2	Cemented iron . .	Ruhrort . .	150	55	95	63·3
3	Puddled steel . .	Hayen . .	12	8	4	33·3
4	„ „ . .	Leudersdorf.	12	8	4	33·3
5	Bessemer „ . .	„ . .	149	142	7	4·7
6	„ „ . .	Essen . .	147	141	6	4·1
7	„ „ . .	Hoerde . .	150	148	2	1·3

Taking, therefore, the mean renewal of Bessemer steel rails after ten years' wear, the result is 3·3 per cent. against 33·3 per cent. of puddled steel rails, 63·3 per cent. of cemented iron rails, and 76·7 per cent. of fine-grained iron rails. The amount of traffic over them during the years 1872–75 was eighteen hundred axles daily, each of an average length of 21 feet 8 inches. The number of Bessemer steel rails laid by the above company from 1868 and the loss by renewals yearly up to 1875 were:—

Year.	Number of Rails laid.	Number of Rails renewed.	Percentage of Rails renewed.
1868	1,853	..	..
1869	21,867	31	0·142
1870	78,259	20	0·025
1871	139,618	54	0·039
1872	222,844	93	0·042
1873	340,300	342	0·101
1874	452,650	738	0·158
1875	504,634	347	0·069
Totals . .	1,762,025	1,625	

This shows an average life of 2½ years.

To admit of a comparison, under equal conditions, a part of the Köln-Minden railway was laid with iron rails (about ⅞ fine-grained and ⅛ fibrous iron) side by side with steel rails. On the 1st of January, 1875, there were 40,980 iron rails, of an average age of 6·98 years, of which during the whole year 2,768, or 6·75 per cent., had to be renewed, while of the 151,306 steel rails, of an average age of 3·8 years, during the same period, only 305, or 0·2 per cent., were rejected. During the first period of traffic it was found that more steel than iron rails were broken. The number of broken steel rails on the whole of the Prussian railways, up to the end of 1874, was 2,920, or 0·21 per cent. of the whole number laid, viz., 1,393,382. Owing to the favourable result of the investigations, the Köln-Minden Railway Company have determined to use Bessemer steel rails exclusively. From 1867 to 1872, only 16,000 tons of iron rails were laid, none since 1872. The weight of steel rails laid since 1867 is 139,000 tons.

Wm. E. T.

Note.—The original does not supply details as to quality of rails or tonnage of traffic, except that the goods traffic is to passenger traffic per axle as 6 to 1.

Wear of Steel Rails in America. By Ashbel Welch.

(Transactions of the American Society of Civil Engineers, vol. v., p. 327.)

Mr. Welch, as chairman of the Committee on the Form, Weight, Manufacture, and Life of Rails, has presented a final report, giving particulars of the behaviour of the steel rails, 53 lbs. per yard, described in his Memoir on rails, read June 10, 1874.[1] Believing that a very thin stem and a very thin base would possess sufficient strength, he designed a pattern in which as much metal as possible should be placed in the head, and as little as possible anywhere else. The height was 4 inches, the width of base 4 inches, the head fully $2\frac{3}{8}$ inches wide and $1\frac{1}{4}$ inch deep, radius of sectional curvature of the head 12 inches, stem $\frac{7}{16}$ inch thick, base $\frac{3}{16}$ inch thick at the edges, angle of base and of under sides of head 14°, length of rails 30 feet, weight 53 lbs. per yard. The rails were rolled by Messrs. John Brown and Co., and were laid in 1867 and 1868, at places exposed to very heavy traffic, on the railway between Philadelphia and New York, where iron rails had lasted only four months: at one place in particular, in Bergen Cut, where the curves are very sharp, and the speed is high. The 53-lb. steel rails have been down since they were laid. In straight portions of the line, after having carried a gross weight of about 50,000,000 tons, mostly at high speeds, the heads have been worn down $\frac{1}{4}$ inch, having lost in weight about 6 lbs. per yard. In some sharp curves, the sides of the heads were so much worn that the rails were taken up in June 1876. The other portions of the rails have never failed.

The maximum percentage of constituent carbon was, in the Report of 1875, fixed at 0·55 per cent., in view of the severe frosts in winter.

D. K. C.

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[1] *Vide* Transactions of the American Society of Civil Engineers, 1875, vol. iii., p. 106. The section of the rails is illustrated in the Paper.

On Rail Joints.[1] By C. P. SANDBERG, Assoc. Inst. C.E.

(Ingeniörs-Föreningens Förhandlingar, Stockholm, vol. xi., p. 77.)

The Author calls attention to the necessity of obtaining a continuous road by making the rail joints as strong and rigid as the centre of the rail. In reviewing previous efforts in that direction, a series of figures are referred to, showing examples of different fish-plates to strengthen the rail joint, both for double-headed and for flange-bottomed rails. The results of experiments with some of these improved patterns are also quoted, such as a rail joint of double-headed rail section with deep fish-plates, the scabbard fish-joint, and the joint with angle fish-plates, or angle and deep fish-plates combined, for use with flange-bottomed rails. The improved form of deep fish-plate, giving greater stiffness to the joint, and suited to double-headed rail sections, is stated to be in use on English lines and to give great satisfaction. It was introduced in France as far back as 1858. The angle fish-plate was tried in Germany in 1862,[2] and is now in use in America. The Swedish Government last year ordered one thousand pairs of each sort for trial on the State railways, and further intended to use fish-plates of angle pattern in order to strengthen the rail joints. The Author compares the stiffness and strength afforded by angle and deep fish-plates with ordinary plain fish-plates, and concludes that an angle and deep fish-plate together would make the rail joint as stiff as the central part of the rail, while offering additional advantages, such as the abolition of the rail-notching, a matter of special importance for steel rails, the road being prevented from creeping by the butting of the deep fish-plate against the joint sleeper. The gauge is better kept by the spikes both inside and outside the rail, and by the wider base side motions can better be resisted. The angle fish-plates have the advantage over the deep fish-plates that they may be laid either as suspended or supported joints, for which reason they would probably be more generally adopted. If a combination of an angle and a deep fish-plate is objected to on the score of complication, it would be easy to adopt either two angle fish-plates, or two deep fish-plates, to form an improved rail joint, and in the latter case the depth of the fish could be regulated so as to give any desired stiffness. It is evident that the angle and deep fish-plates make a stronger rail joint than fish-plates of the ordinary pattern.

C. P. S.

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[1] A translation of this article, with illustrations, has been published in the "Engineer" for November 10 and 17, 1876.

[2] *Vide* Winkler's "Eisenbahnbau," 1871, p. 98.

Re-rolling of Rails in Sweden. By C. P. SANDBERG, Assoc. Inst. C.E.

(Ingeniörs-Föreningens Förhandlingar, Stockholm, 1876, vol. xi., p. 58.)

The Author refers to the discussion on home rail manufacture in Sweden, about 1865, in which the advocates of the Swedish iron trade proposed measures for its encouragement in Parliament and at Engineers' meetings. The Royal Administration for the Government Railways offered to take Swedish rails at 10 to 20 per cent. higher price, and to grant a subsidy for the construction of the necessary works.

A committee appointed by Government to fix the amount of the subsidy made a large number of experiments on foreign and Swedish iron and steel, and although the results did not then lead to any home rail manufacture, their scientific value has been demonstrated by Styffe's work on the subject.[1]

A trial, however, was made at the Motala Works to re-roll a small quantity, partly with puddled and partly with Bessemer steel slabs, and steel-topped rails from this place have given excellent results. At Smedjebacken in Sweden about 5,000 tons of rails have been made chiefly of steel. The great bulk, however, of the rails has been imported mostly from Wales, some from Cleveland and Creusot, amounting for the State lines to 150,000 tons, which, with about an equal quantity for private lines, makes a total of 300,000 tons in the course of twenty years. This, at an average cost of, say, £8 per ton, would give an expenditure of £2,400,000. The breaking of rails is an ordinary occurrence in other countries with a cold climate, and even in England, where during 1875 the Board of Trade reported that there were five hundred instances of broken rails. Though none of the imported iron rails in use on the State lines have broken, yet the imperfection of iron rails from bad welding has reduced their durability for wear, so that only an average life of fifteen years is calculated during the first twenty to thirty years of Swedish State railway construction. It is therefore assumed that 10,000 tons a year would be wanted for renewals, and after the worn-out rails have been applied to station extension, sidings, and bridges, the question what to do with the rest becomes important. It formed the substance of a Paper read before the Institution of Civil Engineers, "On the Manufacture and Wear of Rails," in 1867.[2] The conditions have since been greatly altered, and a large quantity of worn-out rails must be re-rolled or sold at a great loss. Traffic on the Swedish State railways has so increased that a better material than ordinary English iron rails has become a necessity, so that steel is adopted for renewals. At present the proportion of old rails used in the manufacture of new ones does not exceed 20 per cent.; by the plan proposed more than that percentage would be made available. That steel-headed rails have not generally given satisfaction, is in a great measure owing to the difficulty in welding the steel to the iron; but the fall in the price of Bessemer steel rails has left no margin for an extra price for steel-headed rails corresponding to the extra cost of manufacture. Not only is it necessary to use special steel, poor in carbon and rich in manganese, but great care must also be taken in the heating. When steel rails were twice the price of iron rails, there was ample margin for the extra cost of the former. They have, nevertheless, been made in considerable quantities, and there are 3,500 miles of line in Germany entirely laid with them.

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[1] *Vide* "Iron and Steel," by K. Styffe, translated by C. P. Sandberg. 8vo. London, 1869.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 340.

The Author concludes the Paper by giving the basis upon which Government might encourage the re-rolling of rails in Sweden.

C. P. S.

Recent Improvements in Wrought-iron Permanent Way.

By L. Kirsch.

(Revue universelle des Mines, vol. xl., p. 115.)

M. Kirsch refers to his previous communication "On the Use of Cast Iron and Wrought Iron as a Material for Railway Sleepers,"[1] in which he noticed the Vautherin wrought-iron sleeper, the Barlow rail, and the Hartwich and the Hilf systems of wrought-iron permanent way. He accorded the preference to the Hilf system as in every respect the most economical of the metallic systems then described. Composed of a steel Vignoles rail and a wrought-iron longitudinal sleeper, the Hilf system afforded facilities for utilising worn-out wrought-iron rails by rolling them into sleepers. After a period of trial, it has been adopted by the German Government for the State railway from Berlin to Coblenz, Trêves, and Thionville, and it has also been adopted on many other German lines. On the Nassau railway the cost for maintenance of the Hilf permanent way amounted to less than 30 per cent. of the way laid on transverse wood sleepers. On the Belgian Grand Central railway it is one-third. On the Upper Silesian railway it has been ascertained, by comparative trials, that the relative cost of maintenance of the metallic systems of Hartwich, Vautherin, and Hilf were as the numbers 160, 92, 47.

Objections have been made to the Hilf system, that the bolts by which the pieces are united are subject to shearing and to torsional stress, and that therefore a large number of them is required; that these bolts must be introduced from below; that the rail is comparatively heavy; and that on curves of small radius special bolts are required. The greatest objection is the differing positions of the bolt-holes according to the curves of the line, requiring large reserves of material of each kind to be kept at different depots.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 252.

To obviate such objections, M. Kirsch, in conjunction with M. Degreeff, has designed a metallic system, consisting of a steel bridge-rail on an iron longitudinal sleeper. The edges of the flange are turned up, and so form a continuous recess or notch against each vertical side of the rail. It is fixed to the sleeper by means of three pieces—a clamp, a rack, and a bolt. The rack is formed with two snugs on the under side, either of which is dropped into a square hole in the sleeper, upon which the rack lies firmly. The clamp is formed with teeth at one end, on both sides, the teeth on the lower side engaging in those of the rack, whilst the head on the other end is dropped into the groove of the rail. Lastly, the clamp is secured to the sleeper by the bolt, which is introduced from above. Thus all is made fast, and the teeth of the rack and those of the clamp are so graduated that, by reversing the rack end for end, or the clamp either side down, a variety of lateral adjustments of the position of the rail upon the sleeper may be effected in the simplest manner according to the degree of curvature of the line. With this mode of adjustment, the holes in the sleepers may be pierced in the same position for a curve as for a straight line, and the preparations for the fastenings may be completed at the depot.

The first cost and that for maintenance of different systems of rails given by M. Kirsch show the following variations:—

	First Cost.		Annual Cost of Maintenance.	
	Per lineal yard.		Per lineal yard.	
	s.	*d.*	*s.*	*d.*
Vignoles iron rail, 74½ lbs. per yard, with transverse oak sleepers	17	3	2	1
Vignoles steel rail, 76½ lbs. per yard, with oak sleepers	22	2½	2	2¼
Hilf system—Vignoles rail, 52 lbs. per yard, and longitudinal sleepers 58½ lbs. per yard .	23	9	1	8¼
Kirsch-Degreeff system: rail 34 lbs. per yard, and longitudinal sleepers 83 lbs. per yard .	23	1	1	7¼

In the estimates from which these are deduced, there is no allowance for interest on capital for reserve stock, nor for cost of carriage, which is according to the quantity, weight, and durability of the material.

D. K. C.

On the Construction and Working of Narrow-gauge and some other Secondary Railways. By JULES MORANDIÈRE.

(Mémoires de la Société des Ingénieurs civils, 1876, p. 150, 1 Plate.)

The object of this Paper is to collect together the statistics and other information relating to the present position of these railways, the extent of which in each country of the world may be seen from the figures in the following table (A):—

Name of Country.	Number of Miles		Name of Country.	Number of Miles	
	Open to Traffic.	In Construction.		Open to Traffic.	In Construction.
Great Britain . .	26	..	India	820½	1,902
France	43¾	89½	Australia	328	..
Algiers . . .	20½	155½	New Zealand . . .	244	..
Belgium . . .	77	..	Cape of Good Hope .	67	..
Norway . . .	192½	..	Canadian Dominion .	457	373
Sweden . . .	163	..	United States . . .	2,040	7,552
Russia	208¼	..	Central America . .	37¼	155
Austro-Hungary .	52¾	18¾	Venezuela	..	..
Prussia . . .	20	..	Peru	17¼	..
Italy	7½	..	Chili	118	..
Island of Sardinia	18	..	Bolivia	..	155
Switzerland . .	22	..	Brazil	20	411
Greece	5½	..	Havana	..	..
Portugal . . .	..	..	Java	34	..

The above table shows that, during the last few years, the number of narrow-gauge lines has increased enormously. The writer is not of opinion that their adoption in France would be advisable, excepting under special local conditions, and thinks that it would be preferable to retain the ordinary gauge of 4 feet 8½ inches even for the railways of secondary importance, in order to avoid changes of carriages and wagons, but the narrow gauge is advantageous in new countries where the object is to obtain the greatest possible extension of railway communication with a limited amount of capital, and for local purposes, especially for the carriage of mineral or agricultural produce, provided that it has not to be subsequently transferred to the wagons of another railway.

A second table shows the names, lengths, gauge, weight of rails, cost of construction, &c., of the principal narrow-gauge railways in the different countries of the world.

In the following short description of some of these, the four first are laid upon or parallel with turnpike roads:—

Lagny to the Stone Quarries of Neufmoutiers and to *Montcerf* (France).—This railway, 9¼ miles in length, was originally constructed for the carriage of stone only, but afterwards, at the solicitation of the neighbouring towns, passenger carriages were added. It is only 17 miles from Paris, and is frequently visited from thence as a specimen narrow-gauge line. It runs parallel to the high-road, from which it is separated by a ditch, and this allowed of much economy in the purchase of land. The gauge is 3 feet 3⅓ inches (1 mètre) between the rails; weight of rails 32 lbs. per yard; sleepers 2 feet 6 inches apart; width of banks at formation-level 9 feet 10 inches. The locomotives have six coupled wheels, and weigh, including water and coal, from 13 to 14 tons. There are carriages for first, second, and third class passengers, the first with eighteen and the third with twenty-four seats. An extension of 5 miles to Montcerf remains to be finished.

Turin to Rivoli (Italy).—This railway, 7½ miles in length, runs along the side of a broad avenue, and connects Turin with the suburbs. The maximum gradient is 1 in 60; the gauge is 2 feet 11·4 inches (0·90 mètre) between the rails; the weight of the rails is 43 lbs. per yard; the sleepers are 2 feet 8 inches apart. The locomotives have four coupled wheels, and weigh about 11 tons. The carriages are very small, and only allow of three passengers being seated abreast. The average speed of the trains is 12½ miles per hour.

Lausanne to Echallens (Switzerland).—This railway, 10 miles long, is only built on the turnpike road for a certain distance, and for that length it has been necessary to widen the road by about 6 feet in order to leave a clear 18 feet for the ordinary traffic. There is one curve of 66 yards radius and nine of 110 yards; the maximum gradient is 1 in 25 for a distance of 660 yards. The gauge is 3 feet 3⅓ inches (1 mètre). The weight of the rails is 58 lbs. to the yard. The stations consist of two small rooms connected by a third, which is open on the side facing the railway, and they are constructed of wood. There are two locomotives, one weighing 14, the other 8 tons. The speed of the trains is 12½ miles per hour.

The Broelthal railway (Rhenish Prussia) is 20 miles in length, of which 14 miles are on a road and 6 miles in the ordinary way through fields, &c. It was constructed at a total expense of £1,722 per mile; viz., for permanent way, &c., £18,140; for a bridge over the river Sieg £3,540; for stations £5,765; for rolling stock £4,900; for stores, &c. £2,105; making a total of £34,450. A local subvention of £9,000 was granted to the company. The gauge is 2 feet 7 inches.

The Rochebelle railway, with a length of 1 mile 290 yards, carries coals exclusively. The maximum gradient is 1 in 56 for 534 yards; the minimum radius of curve is 66 yards. Very small locomotives are used, which draw twenty empty wagons up the incline; the average speed is 8½ miles per hour. In 1873, 60,000 tons of coals were carried at an average cost of 5½*d.* per ton per mile.

The Mokta-el-Hadid railway (Algeria) is 20½ miles in length, and connects the mines of that name with the seaport of Bona. The gauge is 3 feet 3¼ inches; minimum radius of curves 257 yards; maximum gradient 1 in 117. The original iron rails have been taken up, and the line has been relaid with steel rails weighing 40 lbs. per yard. The sleepers are 2 feet 6 inches apart. Cost of permanent way per yard with iron rails £1 5*s.*; ditto with steel rails £2. The weight of the locomotives (with six coupled wheels) is 16 tons (empty); that of the wooden wagons 1 ton 18 cwt.; that of the iron wagons 2 tons 2 cwt. The rolling stock consists of six locomotives and two hundred and twenty-five wagons. Seven trains, each of forty wagons, run daily in each direction; average speed 10½ miles per hour.

In Norway six narrow-gauge railways, with a total length of 192½ miles, have been opened for traffic, and a further 200 miles are in construction. They are all passenger lines, and have been built by the State. The rails weigh from 35 to 40 lbs. per yard. The gauge is 3 feet 6 inches; the minimum radius of curves is 200 yards; the maximum gradient is 1 in 45; the average speed is 12½ to 15½ miles per hour, including stoppages, that of express trains is 18½ miles per hour. In 1871 the average gross receipts on 144 miles were at the rate of £218 per mile per annum, and the net receipts £45 per mile.

In Sweden fifteen short lines, making a total of 480 miles of narrow-gauge railways, have been built by private companies, and 150 miles are in construction. Five different gauges have been adopted, varying from 2 feet 7 inches to 4 feet. These lines have cost from £1,900 to £3,200 per mile; the average speed is under 15 miles per hour. The rails weigh 20 to 45 lbs. per yard.

The system has been adopted in Sweden of building second-class railways with the ordinary gauge of 4 feet 8½ inches, and with light rails weighing from 40 to 60 lbs. per yard. About 590 miles of such railways have been opened to traffic, and 1,140 miles are in construction. They answer very well. Their average cost, including rolling stock, is £6,400 per mile.

In Russia the railway from *Vierhovie* to *Livny* (38½ miles) and that from *Novgorod* to *Tschudowo* (45½ miles) have been constructed with 2 feet 6 inches gauge. The first has a viaduct over the river Linbovsha, which is 420 feet long, and the gradients rising from this point are 1 in 8 for 7,000 yards in one direction, and for 9,590 yards in the other. The weight of the rails is 45 lbs. The rolling stock of the Livny line consists of two ordinary locomotives, five Fairlie engines, seventeen passenger carriages, and two hundred and sixty-six goods wagons. The same gauge of 2 feet 6 inches has been used on 125 miles of other lines in Russia. They have cost on the average (including rolling stock) at the rate of £6,000 per mile.

In Austro-Hungary gauges of 3 feet 1½ inch, 3 feet 3⅓ inches, and 3 feet 7½ inches have been used on six short lines.

In Switzerland the mètre gauge has been adopted on three short lines, and the 2-foot 5½-inch gauge on a fourth.

In British India 820 miles have been opened to traffic, and 1,900 miles remain to be finished. The gauge is 3 feet 3⅓ inches; the weight of rails 40 lbs. to the yard. Six-wheel locomotives, weighing from 20 to 22 tons, are used. The passenger carriages are made with double sides, and at about 1 foot above the ordinary roof they have a second roof, which projects considerably beyond the lower one to keep off the sun's rays. The first-class carriages are comfortable saloons fitted for seven passengers, and with sleeping accommodation for five. At one end is a retiring room, with washing and toilet arrangements, and at the other a compartment for servants. The cost per mile has varied from £1,088 to £11,392, but the average (including rolling stock) appears to have been about £6,000 per mile.

In Queensland (Australia) 300 miles of railway, with a gauge of 3 feet 6 inches, have been opened to traffic. The weight of the rails is 40 lbs. to the yard. These lines have cost from £4,600 to £11,500 per mile.

In South Australia 28 miles, with 3-foot 6-inch gauge, have been constructed. The weight of the rails is 40 lbs.

In New Zealand, the same 3-foot 7¼-inch gauge has been adopted on 244 miles.

At the Cape of Good Hope 67 miles have been constructed, also with a 3-foot 6-inch gauge. Several hundred miles are in course of construction.

In the Dominion of Canada the same gauge has been adopted on 457 miles of completed railway, whilst a further 373 miles are in course of construction. The average cost per mile of the Toronto-Bruce and Toronto-Nipissing lines, including rolling stock, is stated to have been £3,008; only £448 and £608 per mile on the two lines respectively being charged as expended on rolling stock.

United States of America. A separate table is attached to the original, giving the names and length of sixty-four narrow-gauge railways in the United States, of which 2,039½ miles were, on the 1st of July, 1874, open to traffic, and 7,552 miles in construction. The most important of these is the Denver and Rio Grande railway, of which at that date 161½ miles were finished, and 870 miles in construction. The gauge is 3 feet; the weight of the rails 33 lbs. The first 75 miles cost at the rate of £3,000 per mile, but the remainder, being over rougher ground, has cost £4,000 per mile. In 1873, on 118 miles, the gross receipts averaged £13 per mile per week; the working expenses £6, and the net receipts £7. The rolling stock resembles that on other American ordinary gauge railways; but some Fairlie engines with twelve wheels, and weighing 26 tons, have been adopted. On the Arkansas Central and some other American lines the gauge is 3 feet 6 inches.

In Costa Rica (Central America) a 3-foot 6-inch gauge has been used on a line now in construction from the capital, San José, to the Port on the Atlantic. The rails weigh 42 lbs. to the yard; 37¼ miles are in traffic, and 155¼ in construction.

In Peru a 2-foot 6-inch gauge has been adopted on the Patillos line, the object of which is to carry nitrate of soda from the interior to the coast. The weight of the rails is 35 lbs. This line has some steep gradients of 1 in 28, and Fairlie engines, weighing 26 tons, are used.

It is stated that the latter run on ten other railways. It results from the data supplied in this Paper that the constructors of narrow-gauge railways have adopted almost every conceivable variety of gauge between 1 foot 6 inches and 4 feet. The following twenty varieties will be found in Table C, viz.:—1 foot 6 inches, 1 foot 11½ inches, 2 feet 3⅓ inches, 2 feet 5½ inches, 2 feet 6 inches, 2 feet 6¼ inches, 2 feet 7 inches, 2 feet 7⅓ inches, 2 feet 11½ inches, 3 feet, 3 feet 1½ inch, 3 feet 1¾ inch, 3 feet 3 inches, 3 feet 3⅓ inches, 3 feet 6 inches, 3 feet 7⅓ inches, 3 feet 7½ inches, 3 feet 10¼ inches, 3 feet 11⅓ inches, 4 feet.

Some information is supplied in reference to tramways, especially those in Belgium, and the Author recommends particularly the mode of laying and the description of rail employed on the Liége tramways. Also a large amount of further interesting information on the subject of economical railways generally is contained in the Paper, which the limits of an abstract will not allow of being reproduced.

O. C. D. R.

Railway Constructions in Sicily.

(L' Ingegneria civile e le Arti industriali, vol. ii., p. 49 *et seq.*)

The railway between Catania and Palermo enters the valley of the river Dittano at Sferro, and follows its course to Leonforte. From this station, about 1,100 feet above the sea-level, the line ascends through a mountainous region to Castrogiovanni, about 1,900 feet above the sea, crosses the main mountain-chain, the Sella della Misericordia, through a tunnel of the same name, 4,600 feet long, and descends to the Villarosa station, 1,180 feet above the sea-level. The length of the branch Leonforte-Villarosa is 13·6 miles, and the station of Castrogiovanni is exactly midway.

The mean gradient from Leonforte to the highest point, at about the middle of the Misericordia tunnel, is 1 in 50, the maximum 1 in 36, the minimum 1 in 100 for 300 yards. The mean gradient from the highest point to the Villarosa station is 1 in 46·3, the maximum is 1 in 42·1, and the minimum 1 in 100, for 648 yards. The aggregate length of levels does not exceed 1,150 yards.

Among the embankments, that of Tredici Salme is 885 feet long and 77 feet high; that of Polizzi has a maximum height of 80 feet; others are 68 feet, 76 feet, and 87½ feet high. All these measurements are taken from the central line of the railway; they would be much higher if taken from the point of junction of the slope with the bed of the ravine, which often has a fall of from 1 in 12 to 1 in 3.

The cuttings are from 32 feet to 44 feet deep, also measured from the central line, the higher side being in many instances from 60 to 82 feet above the formation-level. There are three tunnels, 1,560, 810, and 240 yards long. Above the Leonforte station the railway enters upon argillaceous soils of the tertiary age of the miopliocenic period, consisting of sands, blue marl, sulphur, foliated clay, and limestone, irregularly deposited, on account of natural disturbances. Where these did not upset the rocks, the sandy pliocenic strata rest upon the argillaceous marls.

In consequence of hygrometric changes and fluctuations of temperature, the argillaceous marls expand, contract, decompose, and separate, so as to form more permeable strata, of a thickness varying from 6 to 40 feet, which cover the solid rock. These strata are generally unstable, and sometimes quite muddy, as the water dissolves the marl; landslips are therefore of frequent occurrence. They were caused by the bad quality of material; by the unstable soil upon which the embankment was built; and by the condition of the embankment itself. Eight slips were owing to the first cause, eight to the second, two to the third, four to a combination of the first and second, three to the second and third, and six to a conjunction of all. In the case of the slips caused by inferior material, rendered worse by the rainy weather and the frosts that set in during their formation, after clearing away the bad materials, the trench was remade with banks of consolidated earth, upon a bottom of stone ballast, with spurs of stonework interposed. This plan was successful.

The foundation for the ballast was cut in the natural stable soil at the foot of the embankment, with a declivity of 1 in 40 towards the central line of the railway. At the lower side of this foundation a drain was laid for the waters filtering through the stone, and connected with a channel cut at right angles to the railway. The foundation was then filled with stones to a convenient height, and covered with a layer of rammed earth, about 1 foot thick, and also slightly inclined towards the axis of the railway, and upon this other soils were rammed to form the top. Below the foundation ballast a rough wall is sunk, from 1½ to 2 feet thick, to receive and drain waters from permeable strata in the works. At intervals of from 15 to 30 feet a number of spurs are constructed of heavy ballast material, in the direction of the line. They serve as supports to the embankment, and act as an efficient means of drainage. They reach to the top of the bottom ballast, and at times up to the level of the permanent way.

Where good material could be had, the spurs were either abolished or placed at a greater distance apart. When there was plenty of stone and a want of good earth, the bottom ballast was made much higher; on the contrary, when stone was scarce and other material plentiful, they were kept lower, and covered with a layer of faggots. In the embankment of Tredici Salme the depth of the bottom ballast was reduced to 2 feet, and faggots were used to make up the requisite height. When the sides are dry, and the material of the embankment is of the same nature as the ground underneath, the side wall can be dispensed with.

The following general rules were observed for consolidation works. The repair of an embankment that has broken down is commenced simultaneously at several points, 20 to 30 feet apart, the direction of the work being towards the middle, and the slipped material being replaced by new. In constructing spurs and similar work, it is advisable to thoroughly clear the base from all existing mire, as economy of work in such cases has always resulted unsatisfactorily. In summer, when the earth is so dry that necessary cohesion cannot be obtained by the ram, the ground must be slightly watered. These consolidation works never succeeded when constructed during winter or rainy weather, and the same may be said of the drainage channels upon each bank, connected with the main channel, along the foot of the embankment. In places where the natural ground was loose, reservoirs proved successful in arresting the percolation of water. The planting of acacias gave splendid results, not only in preventing the water from finding its way into the embankment, but their immense roots helped to render the works a solid mass.

In the beginning the want of stones was severely felt, and layers of faggots were substituted alternately in longitudinal and transverse directions, each layer separated by a stratum of rammed earth 1 foot 4 inches thick. They were used for the bottom ballast up to a convenient height, and proved successful in the embankments Gussio and Tredici Salme. Their application was, however, not continued as soon as other methods could conveniently be used.

The greatest difficulties in insuring the stability of a trench arise when it is constructed on moving ground. This point, therefore, needs the most diligent study, as the consolidation works in such cases necessitate large expenses. Owing to moving ground, several trenches in the railway branch Leonforte-Villarosa slipped, and others have shown evident signs of instability. In all cases, however, the presence of water in the semi-permeable strata lying immediately upon the hard blue marl proved to be, by repeated tests and by borings, the only cause of the movement of the soil.

With a good system of drains, the water was kept from flowing across a given zone of land, the causes of motion were removed, and the movement arrested of several masses which would otherwise have necessitated colossal works and enormous outlay.

Where the ditches were not more than 26 feet deep, so that the bottom of the drain stood in the stable impermeable soil for a depth of from 2 to 3 feet, they were made open, and with walls either vertical or inclined; but for depths greater than the 26 feet, the well system and tunnelled galleries were found simplest, as they could be carried out in winter and during periods of rain. The Author gives particulars and dimensions of several drainage works, varying in length from 3½ to 6 miles and even 11 miles. The incline of the drains was in no case less than 1 in 50.

The system of wells and covered galleries proved successful even in very shifting soils, and they were easily and quickly constructed. Wells (from 3 to 8 feet in square section) were dug along the proposed line of drainage, at a distance from the axis of 32 feet, with the bottom about 5 feet deep in the impermeable marl. A gallery was then tunnelled between them, and smaller intermediate wells dug along the line at intervals of 16 feet.

When once commenced, it was found necessary to finish the ditches rapidly, to prevent their being damaged by rain. They should always be worked from the lower mountain slope towards the upper. The open trenches should be dug in lengths of 20 feet at a time, to secure rapidity of execution, and to allow of constant supervision, as the works would be irreparably damaged if through negligence or fraud earth and stone were to be mixed, or the foundation was not cut sufficiently deep in the marl. In the works of this railway branch it has been customary to test the drain by pouring in water, and noting in what time it was discharged from the mouth. If the test was successful, a bonus was paid to the workmen. In the case of torrential streams, of which the beds gradually deepened often to the extent of from 3 to 4 feet per year, it has been found useful to construct dams across the stream, and by banking up the water to arrest the flow.

R. Q.

Central-rail Locomotives. By M. Desbrière.

(Bulletin de la Société des Ingénieurs civils, 1876, p. 455.)

Central-rail locomotives are of two kinds, viz.: with two cylinders, and with four cylinders. In the first kind, the power is transmitted direct to the carrying wheels, and, through intermediate levers, to the horizontal or central wheels; in the second kind, one pair of cylinders drives the carrying wheels, and the other pair the central wheels. M. Desbrière prefers the four-cylinder engine for undulating lines of steep railways, as it affords facilities for shutting off steam from the central wheels when their co-operation is not required. For lines of continuous inclination, having an uninterrupted central rail, the recent improvements induce him to prefer the two-cylinder engine, though he admits that experience has not yet decided the superiority of one or the other kind for such a line.

In 1872 the Author gave the Society an account of experiments made with five locomotives for central rails, and with four cylinders each, constructed by Manning and Wardle, of Leeds, for the Cantagallo (Brazil) railway. Two locomotives with two cylinders have since been constructed by MM. Gouin and Co., and have been in service since the spring of 1875, on the Cantagallo railway, the gauge of which is 3 feet 7¼ inches (1·10 mètre). The cylinders are 16 inches in diameter, with a stroke of 18 inches; there are four coupled carrying wheels, 7½ feet from centre to centre, and four coupled horizontal wheels, 2 feet 4 inches from centre to centre, 27 inches in diameter. The effective pressure in the boiler is 135 lbs. per square inch. The weight is 22 tons empty, and in working order, with water and fuel, 27½ tons. There is a weight of 25 tons on the springs of the horizontal wheels, making, with the weight of the engine, a total of 52½ tons of adhesion-weight. The flexibility of the horizontal springs is ⅓ inch per ton. The grate-area is 14¼ square feet, and the heating surface is 777 square feet. The principal novelties in the design of these engines, viz.: those assigned as the cause of their superiority over the two-cylinder central-rail engines made by Gouin and Co., are:—1st. That the guides of the hind carrying axle-boxes are not vertical, but slightly inclined in a position perpendicular to the centre-line of the cylinders. The effect of the oscillations of the engine upon the connecting rod is thus almost entirely prevented, and the breakages of the rod, common in previous engines, have been avoided. 2nd. The vertical axles of the central wheels are maintained in a vertical position, by means of a horizontal disc fixed on the upper end of the spindles, and of such diameter that when a pair of wheels is biting the central rail, the discs are in rolling contact. By the introduction of this expedient, the breakages of the machinery, both inside and outside, have disappeared. One serious defect remained to be remedied—the dispersion of oil from the inside machinery upon the surfaces of the central rail.

The remedy has been applied in four central-rail locomotives with four cylinders, recently completed by the Avonside Company, for the Colonial Government of New Zealand. These engines were built for a gauge of 3 feet 7¼ inches (1·10 mètre), to ascend an incline of 1 in 15, 2½ miles long, with a train of 50 tons. The outside cylinders are 14 inches in diameter, with a stroke of 16 inches. There are six wheels, of which four are coupled, 2 feet 8 inches in diameter, 6 feet 8 inches from centre to centre. The carrying wheels, under the fire-box, have Adams's radial axle-boxes. The inside cylinders are 12 inches in diameter, with a stroke of 14 inches; the horizontal wheels are 22½ inches in diameter, 2 feet 3 inches from centre to centre. There are 13 square feet of grate, and 857 square feet of heating surface. The total weight of the engine in working order is 34 tons, of which 28 tons are for adhesion. The pressure on the central rail is 32 tons, making an available total driving weight of 60 tons. The effective pressure in the boiler is 120 lbs. per square inch. The engines are to work in pairs, coupled together on Stradal's system, so as to make the axles converge on curves. The fugitive oil is intercepted by a sheet of steel, and delivered into cavities in the horizontal wheels. An interesting record of experiments, made at Bristol with these engines, is given, from which it appears that the oil shield has been thoroughly successful, and that the tractive force of the engine is more than doubled by the use of the central-rail system.

The application of sand to the central rail, to assist the adhesion, has been attempted by blowing it against the vertical surfaces, by jets of steam, in the manner of the Giffard injector. The passages are found to become clogged by moistened sand; and it is hoped that compressed air may be successfully employed for the purpose.

D. K. C.

Investigations into the Influence of Gradients and Curves on the Rolling Stock of Railways. By G. Mengel.

(Allgemeine Bauzeitung, vol. xli., pp. 1, 17 and 33.)

In the first part of this treatise the motion of railway vehicles upon an ideal, straight, horizontal track had been considered. The results then found serve also for the present investigation, which commences with the question of curves lying in a horizontal plane. A train, when entering a curve, is acted upon by the centrifugal force, which tends to drive each single wagon in the direction of the radius of curvature. Let M denote the mass of a wagon per axle inclusively, v the velocity of the train, and K the radius of curvature; then the centrifugal force acting upon the wagon per axle is $C = \frac{v^2}{K} M$. Let T denote the total weight of a loaded wagon per axle inclusively, and 32 feet the acceleration of a falling body, then $C = \frac{v^2}{32 K} \cdot T$. This force, C, tends to tip the wagon over the edge of the outer rail of the curve, diminishing the pressure on the inner rails, and augmenting it on the outer. Let H denote the height of the centre of gravity of the wagon above the rail, and w the width of the gauge, then equilibrium will exist between the action of the centrifugal force and that of the wagon-load per axle under the condition that $C H < T \frac{w}{2}$, and the wagon will tip over when $C > \frac{T w}{2 H}$, or $2 H v^2 > 32 K w$. If ordinary values be inserted in this formula, it will be found that a wagon on a curve of 273·4 yards radius will not tip at a less velocity than 2,296 yards per minute, which is out of the question. In fact, the danger in passing quick curves at high speeds depends much more upon the augmented stress on the axles increasing the chances of rupture, and the possibility of the wagons then running off the rails. Let R denote the radius of a wheel, r the radius of a journal of the axle, f the co-efficient of friction for the journal, ϕ the co-efficient of rolling friction, then the motion of the outer wheel of the above-considered axle suffers a resistance from rolling friction equal to $\left(\frac{T}{2}+P\right)\frac{\phi}{R}$, wherein P represents the pressure on the outer rail due to centrifugal force. The resistance offered to the motion of the inner wheel by the rolling friction is $\left(\frac{T}{2}-P\right)\frac{\phi}{R}$. The pressure P is determined by the equation $C.H = Pw$; hence $P = \frac{C.H}{w}$. The action of centrifugal force upon the wagon also changes the resistance $G.\frac{r}{R}.f$, which the friction in the journal opposes to the motion of it (G being the weight of the wagon body).

Let C_o denote the centrifugal force acting upon the loaded body of the wagon, including underframe, &c., then $C_o = \frac{v^2}{K}M_o = \frac{v^2}{32K}\cdot G$; again, let P_o denote the pressure produced by it on the outer journal, then $P_o = \frac{C_o H_o}{w_o}$, in which H_o denotes the height of the centre of gravity of the body of the wagon above the rails, and w_o the distance between the centres of the journals; and the friction in the outer journals $= \left(\frac{G}{2}+P_o\right)\frac{r}{R}\cdot f$, that in the inner journals $\left(\frac{G}{2}-P_o\right)\frac{r}{R}\cdot f$. The combined action of the rolling friction and the friction in the journals is for the outer wheel $\left(\frac{T}{2}+P\right)\frac{\phi}{R}+\left(\frac{G}{2}+P_o\right)\frac{r}{R}\cdot f$, and for the inner wheel $\left(\frac{T}{2}-P\right)\frac{\phi}{R}+\left(\frac{G}{2}-P_o\right)\frac{r}{R}\cdot f$; by the difference of these two forces, viz., $2\left(P_o\frac{r}{R}\cdot f+P\frac{\phi}{R}\right)$, the axle is subjected to a twisting strain whose effect can be determined.

The twisting strain thus exerted upon the axles when sharp curves are being passed, is not the only strain upon them, for there may be a bending strain, and also a combined bending and crushing strain. Thus, if the wheels be considered as firm supports for the loaded axle and for the body of the wagon resting on the journals outside of the wheels, the load upon the outer journal $= \frac{G}{2}+P_o$, and that upon the inner journal $= \frac{G}{2}-P_o$. Those two forces cause a bending of the shaft between the axles. Assuming ordinary dimensions for wheels and axles, a total weight on the axle of 6 tons, and the distance from the centre of the journal to the wheel-boss to be 10·2 inches, the maximum strain thus produced is calculated to be nearly 4 tons per square inch. Again, the combination of a crushing and bending strain arises from the following causes:—The flanges of the outer wheels are pressed hard up against the outer rails by the action of centrifugal force, and the outer rail has therefore to resist this action. This resistance, acting on the wheel as a lever, produces a combined bending and crushing strain on the axle, the amount of which can be calculated, and the maximum proves to be 2 tons per square inch, assuming a velocity of 68·3 feet per second, a radius of 328 yards, and a total weight of 6 tons.

There is a possibility that the axle of a wagon running on a quick curve at a high speed may be subjected at one time to the three different strains described—the twisting, the bending, and the combined strain; but, as a rule, only the twisting and the combined strains will act at the same moment upon the same fibre of the axle. If, however, under particularly unfavourable circumstances, all three strains should act together upon the axle, a maximum total strain

$$\Sigma\,(\mathrm{S}) = \frac{32\left(\mathrm{P}_o \frac{r}{\mathrm{R}} f + \mathrm{P}\frac{\phi}{\mathrm{R}}\right)}{\pi\, d^3} + \frac{32\left(\frac{\mathrm{G}}{2} + \mathrm{P}_o\right) l}{\pi\, d^3} + \mathrm{C}\left(\frac{4}{\pi\, d^2} + \frac{32\,\mathrm{R}'}{\pi\, d^3}\right)$$

$$= \frac{32}{\pi\, d^2}\left(\mathrm{P}_o \frac{r}{\mathrm{R}} f + \mathrm{P}\frac{\phi}{\mathrm{R}} + \frac{\mathrm{G}}{2} l + \mathrm{P}_o\, l + \frac{\mathrm{C}\,d}{8} + \mathrm{C}\,\mathrm{R}'\right)$$

would result for the outer fibres of the axle. In this formula R′ is that radius of the flange which rubs against the rail, *l* the distance between the centre of the wheel and the centre of the journal, *d* the diameter of the axle. As a general rule, axles are subjected to the bending strain alone so long as they are on straight lines, or on curves with a proper elevation of the outer rail, and in that case the greatest strain on the outer fibres is determined by the formula

$$\mathrm{S}_b = \frac{82}{\pi\, d^3} \cdot \frac{\mathrm{G}}{2}\, l = \frac{16\,\mathrm{G}\, l}{\pi\, d^3} = 5\cdot 1\, \frac{\mathrm{G}\, l}{d^3}.$$

In reality, the strain upon the axle is considerably less, as the arm at which the gross load acts upon the journal is the distance from the centre of the journal to the outside face of the boss of the wheel only, instead of the distance between the centre of the journal and the centre of the wheel.

The Author next compares the proportions of wrought-iron and steel axles given by the Society of Managers of German Railways with the results of his formulæ, and finds that for wrought-iron axles they only leave a margin of from 2¼ to 2½ times safety, whereas the cast-steel axles represent a margin of from 8·2 to 9 times safety; in this calculation a strain of 4·4 tons per square inch (or half the proof strain) is taken as the safety strain for wrought iron, and 19 tons per square inch for cast steel. As to the shape of the axle, the Author states that it should increase in thickness from the wheel towards the centre, and by no means diminish so as to be less in diameter between the wheels than in the boss.

The journals are subjected to a shearing and a bending action. Let S_s denote the resistance to shearing in the fibres,

then, $$S_s = \frac{\frac{G}{2}}{\pi r^2} = \frac{G}{2 \pi r^2};$$

and let S_b denote the strain in the outer fibres caused by bending,

then, $$S_b = \frac{32}{\pi d_o^3} \cdot \frac{G}{2} l_o = 5 \cdot 1 \frac{G l_o}{d_o^3},$$

l_o denoting the length of arm at which the gross load is acting, and d_o the diameter of the journal.

On comparing the sizes of journals specified by the before-mentioned Society with his formulæ, the Author finds that those for wrought-iron axles are too weak, representing only 1·2 to 1·4 time safety, whereas the steel journals leave a margin of 4·3 to 4·8 times safety. The above results are illustrated by a table of ruptures of axles on Prussian railways, extending over the twenty years from 1852 to 1872,[1] wherein the broken wrought-iron axles represent 75·6 per cent. of all the broken axles, and the steel axles 24·3; 60 per cent. of all the ruptures occurred in the boss and 30 per cent. in the journals.

After this digression, the principal subject of this memoir—the influence of curves—is again considered. It has already been seen that in curves which lie in a horizontal plane the centrifugal force produces, (1) an unequal pressure upon the journals; (2) an unequal pressure of the wheels upon the rails, causing a twisting strain on the axles; (3) a pressure of the outer wheels against the outer rails, causing a combined crushing and bending strain upon the axles. In order to counteract the damaging effects of these forces upon the rolling stock, an elevation is given to the outer rail in curves. By this inclination of the rails the components of the centrifugal force, and of the weight of the wagon, acting in opposite directions, and parallel to the inclination of the rails, can be brought to cancel each other, equalising thereby the pressures upon the two rails. Let T be the weight of a loaded wagon per axle, C the resulting centrifugal force $= \frac{v^2}{32 K} \cdot T$, w' the width of gauge, β the angle of the inclination of the rails to the horizon, H the height of the centre of gravity of the wagon above the rails, and u the elevation of the outer rail, then the condition under which equilibrium will exist parallel to the inclination of the rails is $C \cos \beta = T \sin \beta$, or $\frac{v^2}{32\,K} = \text{tang}\ \beta$. Hence $\beta = \text{arc tang}\ \frac{v^2}{32\,K}$; also $u = w' \sin \beta$. As β is small, $\sin \beta$ is nearly $= \text{tang}\ \beta$, and therefore the expression may be taken as $u = \frac{w'\,v^2}{32\,K}$. A more exact investigation is given in the Paper, taking into account the fact that, when a wagon is canted inwards to the curve, its centre of gravity describes a path of less radius than when it is on a horizontal plane, and also the tendency of the wagon to slide across the inclined rail and the friction thereby produced. Both these effects, however, turn out to be exceedingly small.

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[1] The proportion of steel and iron axles in use is not given in the table, which is therefore of little value.—W. R. B.

Elaborate tables are given of the height to which the rail should be raised for different speeds and different radii of curve. The elevation can be obtained by three different methods, (1) by raising the outer rail and leaving the inner rail at the ordinary level; (2) by depressing the inner rail and leaving the outer rail at the ordinary level; (3) by raising the outer rail one-half the amount of the elevation, and depressing the inner rail one-half the amount. The best method will be that which causes the centre of gravity of the wagon to deviate the least from its position when entering the curve and when leaving it. If the elevation be given by method (1), the centre of gravity of the wagon when it enters the curve must be raised by $\Delta\,H$, and when it leaves, it must be lowered by $\Delta\,H$, where $\Delta\,H = \frac{w'}{2} \sin \beta + H (\cos \beta - 1)$. If according to method (2), the vertical motion of the centre of gravity of the wagon is $\Delta_1\,H = \frac{w'}{2} \sin \beta + H (1 - \cos \beta)$. If according to method (3), $\Delta'\,H = H (1 - \cos \beta)$. It will be seen that (2) must be abandoned, as the motion is greater by $\frac{u}{2} = \frac{w'}{2} \sin \beta$ than that of (3). The decision as to the two others depends on whether $\Delta'\,H \overset{<}{\underset{>}{=}} \Delta\,H$. In practice the preference will generally be given to the first method, mainly for the sake of convenience. It is of importance that the curve should have the same uniform elevation throughout, and that the elevation required for the highest speed should be employed, as slower trains, especially goods trains, take no harm from too much elevation, whereas express trains are exposed to running off the line in consequence of too little elevation. It is important that the full elevation should be given at the commencement of the curve, and that this elevation should be gradually attained in the curves of adjustment, or if there be none, with a gradient of 1 : 197·74 in the direction of the straight line.

As the elevation is dependent on the speed, and principally on the width of the gauge, the latter has to be increased in curves, the maximum increase allowed by the Society's rules being 1·18 inch in curves of 197 yards radius. This increase is dependent on the following quantities, viz., the ordinary width of the gauge, the radius of the curve, the wheel base, and the depth and play of the flanges of the wheels. Let R denote the radius of the wheel, Δa the distance between the vertical through the centre of the wheel and that part of the flange which comes in contact with the head of the rail when running on a curve; and assume that the depth of that point below the face of the rail be 1·18 inch (30 millimètres), and that the total play between the flange and the rail be 0·39 inch (10 millimètres) in straight lines, as well as in curves, divided equally on both sides, then $\Delta a = \pm \sqrt{(R + 0\cdot 03)^2 - R^2}$.

The position of the points of contact between the flange of the wheel and the rail forms the basis of the calculations for the increase in width of gauge in curves. This is considered (1) for wagons with two axles; (2) for wagons with three axles, the middle axle being either a fixture or movable; and (3) for wagons with four axles, or American wagons with bogies.

(1) Width of gauge for wagons with two axles. Let a denote the distance between the axles or the wheel base, and $a + 2\,\Delta a$ the distance between the two points of contact of the wheels and the rails on the outer rail, and $a - 2\,\Delta a$ the same for the inner rail; and let the play between those points of contact and the rails be equal to the play in an ordinary straight line of rail; then the distance between the points of contact on the wheels belonging to the same axle is equal to the ordinary width of the gauge. There remains to be determined the actual width of the gauge in curves which may be called $w + \Delta w = w_\Delta$; Δw representing the increase in width of gauge. The points of contact on the outer rail lie upon an arc whose radius is $K + \frac{w_\Delta}{2}$, and those on the inner rails upon an arc of the radius $K - \frac{w_\Delta}{2}$. The versed sines of those arcs are for the outer points of contact $p_o = \left(K + \frac{w_\Delta}{2}\right) - \sqrt{\left(K + \frac{w_\Delta}{2}\right)^2 - \left(\frac{a + 2\,\Delta a}{2}\right)^2}$, and for the inner points of contact $p_i = \left(K - \frac{w_\Delta}{2}\right) - \sqrt{\left(K - \frac{w_\Delta}{2}\right)^2 - \left(\frac{a - 2\,\Delta a}{2}\right)^2}$. Hence the width of gauge for the curve will be $w_\Delta = w + p_o - p_i = w + \frac{2\,a\,.\,\Delta a}{2\,K + w}$, and the increase in width of gauge $\Delta w = w_\Delta - w = \frac{2\,a\,.\,\Delta a}{2\,K + w}$.

(2) Width of gauge for wagons with three axles. In the case

of the three axles being fixtures, the outer, fore, and hind wheels, and the inner middle wheels only come in contact with the rails; then $w = \sqrt{\left(K + \frac{w_\Delta}{2}\right)^2 - (a + \Delta a)^2 - \left(K - \frac{w_\Delta}{2}\right)}$. Hence the width of gauge $w_\Delta = w + \frac{(a + \Delta a)^2}{2K + w}$, and the increase $\Delta w = \frac{(a + \Delta a)^2}{2K + w}$. In case the middle axles turn on a swivel, the wagon may be considered as having only two axles.

(3) Width of gauge for wagons with four axles, or bogies. These may be treated in the same way as two wagons with two axles coupled, and the above formulæ will apply by calling a the distance of the axles in one bogie. A table of widths of gauge for different curves is given.

On comparing the widths of gauge for wagons with three axles, in the case where the middle axle is fixed, and in the case where it is movable, the difference of the gauges in the two cases is found to be $\frac{(a + \Delta a)^2}{2K + w} - \frac{4a\Delta a}{2K + w} = \frac{(a - \Delta a)^2}{2K + w}$, which shows how undesirable wagons are that have fixed middle axles.

The Author next contrasts the results of his formulæ with those generally laid down, and states that the latter give too great widths for wagons with movable middle axles, and too narrow widths for wagons with fixed ones; and the same with relation to the elevation of the outer rail.

The bad effects of a faulty width of gauge and elevation are manifest by considering the knocking to and fro of the wagons when running through a curve, where the wheels have a play of 1·5 inch, for instance, when 0·79 inch would be amply sufficient. The knocking of the wagons is the more violent, the more the elevation of the outer rail corresponds correctly to the speed, the pressure in that case being equal on both the rails; for if the elevation is more than is required for the speed, the inner rails are subjected to greater pressure and to a greater rubbing of the flanges of the wheels than the outer rails, and if the elevation is less than necessary for the speed, the same takes place with relation to the outer rail. The consequence in both cases is a steadier motion of the wagon, on account of the pressure of the flanges against the rails. An incorrect elevation, therefore, is partly neutralised by a steadier motion of the wagons, but at the expense of all the working parts. An incorrect increase in the width of the gauge may be neutralised on curves by an incorrect elevation of the outer rail, but not on straight lines. A considerable number of railway accidents, where inquiry fails to detect any visible cause or fault, such as rotten sleepers, &c., in the permanent way, may be put down to a fault of gauge. For all wagons with two axles, and for all with three axles, where the middle one is movable, and for all American wagons with bogies, an increase of 0·28 inch in the width of the gauge on the quickest switch curves is sufficient.

For wagons with three or more fixed axles the necessity of increase in the width of the gauge grows rapidly, so that the maximum amount specified by the Society, 1·18, is not sufficient, if the condition is to be observed, that the wheels should have the same play in curves as they have in straight lines. Generally it may be said that wagons with two axles, and American wagons, are to be preferred to wagons with three axles, even if the latter are provided with a movable middle axle, as the distribution of the load is under all circumstances more difficult and more unequal.

The Paper is concluded by an elaborate table of the numbers, breakages, &c. of rolling stock on the Prussian railways from 1852 to 1873.

W. R. B.

Wire Tramway at the Hanover Gasworks.

(Journal für Gasbeleuchtung, vol. xix., p. 633.)

On the 21st of September the wire tramway from the Hanover railway station at Küchengarten to the Gasworks was officially opened. The line has been constructed to carry coal to the gasworks, and to bring back coke to the station. Fifty tons of coal, loaded in five wagons, which stood on the gas company's railway siding, were transferred to the small hanging trucks. At two o'clock p.m. these were started, and the last was discharged at the gasworks in less than three hours.

This wire tramway was constructed by Mr. A. Bleichert, Engineer of Leipzig. It commences at the Küchengarten goods station, and runs for 192 yards straight and parallel to the railway, the upward incline being 1 in 20. The line then makes an angle of 135°, crosses the railway and a road, and runs straight, and with a slight incline, to the left bank of the Ihme river; here it has another bend of 122°, crosses the river in a clear span of 171½ feet, and the main line ends on the right bank close to the retort house of the gas company, its length up to this point being 633 yards. A second distributing line commences here, about 555 yards long, constructed to carry the trucks into the several retort houses and coal stores.

The traction rope is put in motion by a steam engine of 4 HP. at the upper station, but only half this power is required at present. The speed transmitted by it to the trucks can be varied, but averages 5 feet per second, or about 3½ miles per hour; but the carrying power of the line can be largely increased, both by increasing the speed and by adding more trucks. At present 170 tons of coal are carried per day of ten hours at the above speed, and this represents the minimum of what can be done.

Some of the trucks are loaded with coke at the retort houses, and are tipped into the railway wagons at the station siding. The handling of the trucks, breaks, &c., requires only ordinary intelligence, and is therefore independent of specially skilled labour.

E. D'A.

[In a letter to the Sec. of the Inst. C.E., dated Gas Works of the Imperial Continental Gas Association, Hanover, November 17th, 1876, Herr L. Körting says:—

"The cost of working is as follows—

	Marks or Shillings.
A. Bringing of full railway wagons to filling-shoot, throwing of the coals on to shoot, and taking empty wagons away per 100 cwt. of coals,	0·70
B. Service of tramway: 3 men to fill wagons, coupling with rope, and receive empties. 2 men to turn wagons at first curve. 2 „ „ „ second „ 2 „ at receiving station, who also look after steam engine, &c. 4 „ to take the wagons to coal-sheds and retort-houses. 1 man to trim coal in coal-sheds.	
14 men at 2*s.* 6*d.* a day = 35 marks. The tramway can carry 3,500 cwt. per day of 10½ hours, but taking into account loss of time, it is put down at 2,800 cwt., cost per 100, $\frac{35}{28}$	1·25
C. Cost of oil	0·05
D. Cost of steam engines is difficult to determine, with the otherwise large consumption of steam, but it may be put at per 100 cwt.	0·20
	2·20
Former cost per wagon	4·40
Saving	2·20

The capital for construction was—	M.		£.
Land for the way	21,000	or	1,050
Land at the station	3,000	„	150
Entire iron-work of the railway	24,000	„	1,200
„ wood-work, curves, and supports	4,000	„	1,200
„ masonry-work	3,000	„	150
	75,000		3,750

"With a yearly consumption of coal of 500,000 cwt., the saving will be 5,000 × 2·2 = 11,000 M. or £525. For interest and amortisation, therefore, there will be $\frac{3,750}{525}$ = 14·7 per cent.

"This calculation does not include the gain from the transport of coke and tar to the railway. This will in any case exceed the cost of repair, which is also not included."]

The Tiber and its Delta. By PROFESSOR PONZI.

(Rivista marittima, vol. ix., p. 38.)

In a former Abstract[1] an account was given of the hydrometric observations on the river Tiber by Angelo Vescovali. The present Paper deals with another chapter of the same subject, and is illustrated by four beautiful plans, which not only serve to explain the statements of Signor Ponzi, but are valuable as throwing light on the researches of Signor Venturoli, cited in the former Paper, and on any study of the course and history of the river Tiber and its embouchure.

In the Bulletin of the Italian Geographical Society for 1875, vol. xii., Professor Ponzi, a senator of the kingdom of Italy, published a Paper on the natural history of the Tiber. This was followed, on the occasion of the International Geographical Congress which assembled at Paris in 1875, by another monograph by the same author, on the Delta of the Tiber. These works having been much sought for, the Author has reproduced them, with alterations and additions, in the present article. The object proposed by Signor Ponzi is to make the Italian coasts, especially that of the Tuscan Sea, better known.

The first Paper commences with a minute topographical account of the basin of the Tiber, and of the course of that river and its affluents. This is illustrated by a map, of which the scale is not mentioned, but which is apparently that of about 2½ inches to a degree. The map shows the main chain of the Apennines, from above Citta di Castello to the Lago di Fucino, which forms the eastern limit of the Tiber watershed; the southward range of mountains running from the heights of Alvernia, in Tuscany, which bound the upper part of the same basin on the west; and the four volcanic craters of Vulsinio, Cimino, Sabatino, and Laziali, which occur in a line parallel to that of the main Apennine range. Neither areas of watershed basin nor lengths of rivers are given.

From the topographical features of the present day the Author passes to an investigation of the condition of the same locality in the miocene, pliocene, diluvial, glacial, alluvial, and modern geological epochs. This interesting *excursus*, which is illustrated by coloured hydrographic plans of the locality, in the pliocene epoch, and in the epoch of subterranean volcanoes, is of geological rather than of engineering interest.

The positive historic facts which date the growth of the delta of the Tiber are headed, according to Signor Ponzi, by the foundation of the town of Ostia by Ancus Martius, fourth king of Rome, in the year 633 B.C. Dionysius of Halicarnassus and Lucius

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 356.

Florus are cited as authorities for the statement that Ostia was then built at the very mouth of the river, as to which their language is positive. The ruins of ancient Ostia exist, and furnish a point from which to measure the growth of the delta. No monumental determination of the position of the mouth of the Tiber during the republic is known, but Strabo (lib. v., cap. iii.) mentions the fact that Ostia had been deprived of her port by the deposits caused by the Tiber and its affluents; and that in consequence vessels were compelled partially to unload their cargoes in the open sea in order to ascend the river to Rome. The great supply of corn from Egypt took this route. Plutarch ("Life of Cæsar," c. lviii.) says that Julius Cæsar intended to remedy the evil by deepening the mouth of the Tiber and forming a port, but that his death prevented the accomplishment of the design. Under Claudius the danger of famine from the difficulty of navigation had so much increased that rewards were offered for the transport of provisions to Rome during the dry season. Claudius presented to the Senate a project for forming a port at Ostia; but as the scheme involved great difficulties, the emperor abandoned it, and substituted that of a port on the right side of the delta, at a distance of 2 miles from the Ostian mouth. A basin was here constructed, protected by two moles and a breakwater; and provided with towers and a lighthouse, and with a canal that put it in communication with the river. That work, commenced by Claudius, is said to have been completed in the first year of the reign of Nero, A.D. 54. The traces of these great works are still visible on the ground.

In the reign of Trajan, within half a century from the completion of the Claudian port, the process of deposit had so far advanced that the navigation was rather impeded than otherwise by the late works. Trajan repaired the port, adding an internal basin of an hexagonal form; which now, reduced to a marsh or little lagoon, still retains the name of the *Lago di Porto.*

An extraordinary inundation of the Tiber is mentioned by the Younger Pliny ("Letter to Macrinus," book viii.) as occurring in the reign of Trajan; which emperor opened a new mouth for the river, from a point where, above Ostia, it curved suddenly to the south. That point is still known as the *Capo Due Rami*, or head of the two branches. The opening of this new line of discharge, known as the *Fossa Trajana*, is referred to the year 110 A.D. The present length of this canal, which enters the sea below Fiumicino, is about 2½ miles.

The next monuments which denote the advance of the Tiber delta are the towers which were erected by successive popes on the margin of the sea for the defence of the shore. Of these the most ancient is the tower of Pope Nicholas V., which was erected on the right bank of the Tiber in the year 1450, at a distance of 163 yards from the work of Trajan, to guard the coast from the disembarkation of the Saracens. There is some doubt as to the identification of the ruins of this tower.

The next chronological indication is furnished by the octagonal tower of St. Michael, erected in 1569 by Pope Pius V., on the left bank of the Tiber, according to an inscription on a stone above the gateway. The tower called Alessandrina, on the right bank, was erected by Pope Alexander VII. in the year 1662, and subsequently used as a custom-house. Finally, the tower of Fiumicino, named Clementina, was founded by Pope Clement XIV. in the year 1773, according to an inscription above the gateway, on the side of the stream and on the edge of the sea.

		Years.		Yards.		Yards per ann.
From Ancus Martius to Trajan	elapsed	743	advance	1,035	average	1·4
„ Trajan to Pius V. . .	„	1,459	„	1,907	„	1·3
„ Pius V. to Alexander VII.	„	93	„	600	„	6·4
„ Alexander VII. to Clement XIV. . . .	„	111	„	490	„	4·4
„ Clement XIV. to 1874 .	„	101	„	477	„	4·7
Total		2,507		4,509	„	3·64

The marked difference in the rate of advance between the period preceding and that following, the completion of the work of Trajan is referred by Signor Ponzi to the influence of volcanic action in raising or depressing the coast line with regard to the level of the sea. That action, from the date of the foundation of Ostia to the time of Pius V., the Author considers to have been but trifling. From the pontificate of this pope to that of Alexander VII., the elevating action was notably increased; diminishing again in the succeeding period, but still perceptible with the actual advance of 4·3 yards per annum. The marks of the action of marine molluscs, in boring rocks now far above the level of the sea, are referred to in support of the theory of successive and variable elevations of the soil of the shore of the Tuscan Sea.[1]

F. R. C.

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[1] In the earthquake of 1857, which was chiefly felt in the province of Basilicata, where as many as 30,000 people are said to have perished, the entire coast of the Bay of Naples, from Sorrento to Misenum, was raised 8 inches above its former level in a single night, and maintained that elevation.—F. R. C.

Quay Walls at Rotterdam.

(Deutsche Bauzeitung, vol. x., p. 263.)

Opposite the town of Rotterdam, on the left bank of the Meuse, is the peninsula of Feijenoord, occupied by a large shipbuilding and iron-works company, by a station of the Dutch State railway, and by private and public buildings in connection with the trade of the port. The railway possesses a large dock, the "Spoorweg-haven," 1,312 yards long and 109 yards wide. The Rotterdam

Trading Company is now constructing a second basin about 1,092 yards long and from 43 feet to 82 feet wide. Both these docks are open or tidal basins; the average rise of tide is only 3 feet 7 inches; the lowest tide in 1872 was 2 feet 9½ inches below zero, and the highest spring tide 5 feet 11½ inches above zero; the extreme range is therefore nearly 9 feet. The flood tide runs for four hours, the ebb therefore about eight hours twenty minutes; the current is not strong. The nature of the soil is most unfavourable. Piles, 62 feet 4 inches long, were driven without reaching solid ground; the soil is hardly strong enough for ordinary banks, and good sand has to be brought from a distance. It was therefore impossible to erect substantial quay walls on a masonry substructure, and piling was chosen as the only means of securing a permanent foundation. The construction adopted for the new basin is almost the same as the one used for the Spoorweghaven, and is intended not only to secure the bank, but also to supply a wide quay, and considerable storage room for raw products and other goods.

The bottom of the basin is 19 feet 8 inches below zero, the top of the quay wall 9 feet 2 inches above it, the natural surface of the ground being about 9 feet 10 inches below zero. First, a wide ditch was dredged out to 23 feet below zero, with a slope of 1 to 1 both ways: this was filled with sand as soon as the mud was got out. Eight rows of piles were then driven, 4 feet 4 inches apart from centre to centre both ways, the front row being in line with the intended quay wall. These piles were from 52½ feet to 65½ feet long, and were cut off at the level of 4 feet 3 inches below zero. At a level of 11 feet 6 inches below zero, strong longitudinal bracing was introduced on both sides of each row of piles, and on the inside of the fourth row from the front a complete longitudinal wall of planks, 3·15 inches thick, was erected parallel to the face, in order to ease the thrust on the front piles. Similar cross walls were run from this to the face at every third row of piles, thus dividing the front half of the quay into a number of small compartments. The object of this was to diminish the effect of the current on the material of the slope, which was then completed from the level of 11 feet 6 inches below zero down to the bottom of the basin, and protected by a slight face and footing of stones. A substantial grid was constructed on the piles, and a platform of double planking, 3·15 inches thick, laid on it, braced horizontally above and below. The masonry wall was commenced over the whole width of 29 feet 6 inches, and carried up to a height of 1 foot 7 inches; the remainder of the height was, however, to be used as a warehouse. The foundations were stepped off in front and rear, so as to leave a face wall of 3 feet 11 inches thick at 1 foot 7 inches below zero, and a rear wall of 2 feet 6 inches at the same level. The remaining clear space of 22 feet 7 inches was divided into three parallel galleries, by rows of columns resting on masonry, also stepped up from the foundations, so that the vertical section of the whole quay shows, roughly, two right-angled triangles on the face and rear, and two isosceles triangles filling up the space between them, and capped by the columns. The intervals between these triangles were filled up to a level of 1 foot 7 inches below zero, for the floor of the warehouse. The columns consist of 4-inch gas-pipes filled with cement, resting on square cast-iron ribbed bed-plates, supplied with similar cast-iron caps. The latter carry rolled cross and longitudinal girders on which the road is laid. The Author indicates a batter of both face and rear walls, but the sketch is on too small a scale for the dimensions to be measured. After the completion of the masonry foundation, the slope was finished under the grid up to the fourth row of piles, and was covered with stones; earth was filled in behind up to the zero mark, and the rest of the basin was excavated.

The Author calculates the extreme load which can possibly come on each pile, and estimates it at 116 cwt.; which, reduced to square inches, and assuming the piles to average 12 inches diameter, is almost exactly 1 cwt. per square inch.

E. D'A.

The Bremen Waterworks.

By E. Bötcher and H. Ohnesorge.

(Zeitschrift für Bauwesen, vol. xxvi., p. 343.)

The following were the chief points laid down, before this work was commenced, by Herr Berg, chief architect to the town. As the number of inhabitants was about seventy thousand, provision should be made for a supply of 900,000 gallons per diem. A reserve machine should, however, be provided, capable of pumping another equal quantity; and in laying the pipes, provision should be made for an increase in the supply, and for an eventual doubling. The level of the highest inhabited part of the town is 39 feet above Bremen datum.

It was at first proposed to procure the supply from the ground by natural filtration, but experiments showed that such water could not be used. It was found that the river was perfectly free from metallic salts in solution, but that after filtration through the clay bed sulphuret of iron (Schwefeleisen) appeared in appreciable quantities. It was therefore determined to obtain the water from the river, and to purify it by artificial filtration.

The works are situated on a small peninsula formed by the junction of the great and small Weser. They consist of a handsome square building containing the pumping machinery, and two large water-tanks placed 128 feet above datum. The building has four towers, which are respectively appropriated for the chimney-shaft, the falling and rising mains, and the staircase. On one side of this building is the boiler-house, and on the other corresponding to it a dwelling. Behind these is a large covered reservoir and filtering basins. The water is obtained from the Great Weser, and is admitted by a pipe into a well, from which it is pumped into the filtering basins; thence it passes into the covered reservoir, and is pumped into the tanks and into the pipes.

The filtering basins have each an area of 808 square yards. The sides and bottom are of bricks set in trass mortar, and plastered over with Portland cement mortar. The bottom bend is 9·17 feet above datum. The following is the arrangement of the filter layers and their respective thicknesses, beginning from the bottom:—

a. Coarse shingle in thickness of	. . .	20·87 inches.
b. Middling ,, ,,	. . .	7·56 ,,
c. Fine ,, ,,	. . .	5·71 ,,
d. Coarse gravel ,,	. . .	5·71 ,,
e. Fine ,, ,,	. . .	5·71 ,,
f. Fine sand, washed ,,	. . .	28·47 ,,

The top level of the sand layer is, therefore, 15·30 feet above datum.

Experience has shown that the deposited matter does not infiltrate beyond 1 inch, and it then forms such a dense crust that the filtering basin cannot be further used until it is removed. This is easily done by sod-cutters, and can be repeated for some time before the sand need be replaced. The pipe by which the water is admitted is 14·85 inches in diameter; its position being vertical, with a trumpet-shaped mouth. The water, having passed through the filters, is carried off by nine small channels into one larger, whence it passes into the covered reservoir through a stand-pipe having two outlets; one level with the bottom, and the other about 11 inches below the ordinary water-level of the filtering basins. When filtration is proceeding rapidly, the latter is used; when slowly, the former, by which the rate can be kept nearly uniform.

The covered reservoir has an area of 1,600 square yards, exclusive of the pillar space. The bottom, which is 7·4 feet above datum, is covered with a layer of Portland cement mortar, 1 inch thick. To protect the water in the reservoir from frost, it is arched over between iron girders, and these arches are covered with a layer of clay 3 feet thick. The main building had to be erected on piles, and its size was dependent on the two tanks placed 128 feet above datum.

The sizes of the pipes in use vary from 20 inches to 3 inches. They are socket pipes, and their lengths and dimensions are given in detail. Hydrants for a 2½-inch hose are placed about 100 yards apart. One hundred and twenty fountains have also been provided for free use. The pipes were tested to 15 atmospheres; and at 12 atmospheres they were rapped with hammers varying in weight from ½ lb. to 3 lbs. The water has to be taken over two bridges; and from the construction of the largest one of them, the pipe of 19·8 inches diameter is split into three small ones of 13·88 inches diameter, one of them being a reserve pipe. It also passes underneath the timber harbour for 45 yards through wrought-iron pipes. The laying was done by Messrs. J. and A. Aird, between November 1872 and April 1873.

The five Cornish boilers are usually fed by the donkey in the engine-house, but have also an independent steam-pump. The steam-chest is placed across the end of the boilers, and the steam-pipe goes along the top of the flue into the engine-house. The chimney-shaft is 3·78 feet in diameter, and is constructed of fire-brick masonry to 39 feet above datum, from whence the remaining 136 feet are formed by a cast-iron pipe.

The two double-cylinder horizontal steam-engines are exactly similar. The diameter of each cylinder is 19·5 inches, and the stroke 58·5 inches. The piston-rods of each are prolonged, the one working a so-called filter pump, the other a high-pressure pump. Each engine has its condenser, and works an air-pump, a feed-pump for the boilers, and a small air-pump for the air pressure in the mains.

The filter pump has a diameter of 18 inches, and a stroke of 58·5 inches. It lifts the water from the well in communication with the Weser; draws it through two air-vessels, from whence it flows by a pipe 20·82 inches in diameter, and common to both engines, into the filtering basins. The lift is usually about 15 feet, and the quantity discharged per minute 1,540 gallons.

The high-pressure pump has a diameter of 17·86 inches, and a stroke of 58·5 inches. It lifts the filtered water out of the covered reservoir in a similar manner through a 14·85-inch pipe, and into the rising main, and thus into the tanks above. The lift is usually about 120 feet; and the quantity raised per minute 1,500 gallons.

Details are given of the various steam and pipe arrangements. The rising main is 20·82 inches in diameter, and the falling main 19·81 inches. They are both constructed of flange pipes, and have the necessary compensating arrangement under the tanks. The engine-room contains self-registering gauges of the water-level in the five filtering basins and the reservoir, and a bell which rings as soon as the tanks are full. There are self-registering gauges of the water-level in the tanks and in the well, as well as a manometer giving the pressure in the rising main.

Experiments were made to test the guaranteed coal consumption with very satisfactory results; the quantity of coal required to raise 220 gallons 120 feet being 0·776 lb. (34,000,000 of duty).

The size of the tanks is 73 feet by 35 feet, by 11 feet high, and they are able to contain 372,500 gallons of water each. They are constructed of iron plates, with angle-iron ribs 6·4 feet apart. The total weight of each is about 80 tons. Each rests on nineteen cross girders, constructed to carry 3·7 tons. These rest on fourteen principal girders, with a span of 40 feet. The width of one of these girders in the centre is, in proportion to its length, as 1 to 8. Its lower side forms a parabolic curve, joined to the upper horizontal side by seven uprights, which are joined to each other by diagonals. They rest at each end on cast-iron blocks which work on rollers, and so allow for the consequences of change of temperature. The total weight of all the girders is about 180 tons.

The cost of the work was £152,250. E. E. S.

The Waterworks of Frankfort on the Oder.

By F. Schmetner.

(Deutsche Bauzeitung, vol. x., p. 225.)

The town of Frankfort on the Oder has a population of 45,000; it consists of two parts,—the upper and lower town, separated by a steep rise, on which are but few buildings. The lower town is much larger than the upper, and lies on a level of from 19 to 26 feet above zero mark of the river, the soil being heavy clay without water. The upper town is 65 feet to 78 feet higher. It was determined to distribute the water from two reservoirs at different levels, so as to obtain, even during the greatest consumption, a pressure of at least 65 feet above the street-level.

As no springs were to be found in the neighbourhood affording a sufficient supply, it was resolved to collect the subsoil water from the valley of the Oder immediately above the town by means of four wells and a collecting drain 328 feet long, the water being raised by two pumping engines into the distributing reservoirs. There were two reservoirs, one for the lower town in excavation, the other for the upper town, constructed on a masonry tower. Their capacities, intended to compensate the inequalities in the quantity of water used up to a maximum of 2,200,000 gallons daily, were fixed at 264,000 gallons for the lower and 88,000 gallons for the higher one. The height of the lowest water-level above zero is, in the lower reservoir, 144 feet 4 inches, in the higher one 205 feet. The gravel stratum from which the water is taken extends from a considerable depth to 3·28 feet above the zero level, and is covered by about 3·28 feet of clay. The water-level in the river varies from a little above zero to 19·024 feet, and the subsoil water moves with it. The collecting drain is constructed of concrete blocks. It has an inside diameter of 1·64 foot, but, for convenience in laying, it is square on the outside, the length of a side being 2·296 feet. Thus the thickness of concrete at the crown and at the springing of the arches is only about 4 inches. The concrete blocks were each 3·28 feet long, and laid dry, breaking joint. Each block has twenty-four holes, 1 inch wide, for the water to percolate. The blocks were made on the works; none broke either during manufacture or construction, and in the opinion of the Author they are as cheap as clay pipes, and stronger. Three of the four wells are 3·28 feet in diameter, with porous walls, one brick thick, so as to serve as collectors; while the fourth well contains the suction pipe of the pumps. The floor of the invert of the drain is 4·592 feet below zero level, and therefore about 6·56 feet below ordinary low water. It was at first intended to construct a much greater length of collecting drain, but as pumping to the extent of 70,532 cubic feet per hour reduced the level in the main well by 3·28 feet only, while the drain was still full of water, the length executed appeared amply sufficient.

As it was necessary to provide for pumping the drain quite dry in case of need, the total variation of the suction-level extended from 6·56 feet below to 19·68 feet above zero; that is, to 26·24 feet. Yet the floor of the engine-house and the principal parts of the engine could not safely be erected below the 19·68-foot level, in order to avoid injury by the frequent floods. The usual type of a horizontal engine, which would have involved a lift of about 29·52 feet, was therefore abandoned in favour of a direct-acting vertical engine. The centre of the pump is placed at 9·84 feet above zero, so that the greatest lift can never exceed 16·4 feet. The engine-house floor is 19·68 feet above zero. The engines are compound on Woolf's system, the large cylinder having a diameter of 31·497 inches, and the small one of 15·748 inches; the former drives the plunger of the water-pump directly, the latter the air-pump. The length of the stroke is 37·796 inches, the diameter of the suction and pressure pipes is 11·811 inches. There are two sets of engines, each of which can pump into either reservoir; each engine works up to 70 HP., making eighteen revolutions per minute. There are four Cornish boilers, in a house of which the floor was laid at only 16·4 feet above zero for the sake of economy, the floods which exceed that level being of very short duration, and it being, in the opinion of the Author, possible to keep the water off the boilers by a miniature bank round them.

The high-level reservoir is carried on a round tower, 52·48 feet high, to the cistern floor; this is strengthened by four radial walls 3·28 feet thick, and is constructed of ordinary bricks laid in white lime mortar. The reservoir is carried by rolled girders; it is constructed of iron plates 0·472 inch thick in the floor and lower courses, 0·315 inch higher up, and is covered by a tent roof of iron weighing about 34·5 lbs. per square yard. An inner cover of boards is provided to keep the heat of the sun off the water. The distance of this reservoir from the engine-house is about 700 yards, and a ball valve, provided with a staff and flag, shows the overseer at the engine-house the level of the water in the reservoir.

The cost of the engine-house, including boilers, boiler-house, coal-shed, and chimney, was £3,990; of the engines and connections, with pumps, £7,385; and of the high-level reservoir, including building and iron, £5,415.

The works have now been in use twenty months, without any interruption of the water supply, which has averaged 1,540,000 gallons per day.

E. D'A.

The Failure of the Worcester Dam, U.S.A.

By Messrs. Ellis, Greene, and Wilson.

(Transactions of the American Society of Civil Engineers, vol. v., p. 244.)

The Worcester dam, constructed in 1870–71 on the Lynde Brooke, formed a reservoir of 132 acres, containing 663,330,000 gallons of water. The main part of the dam runs east and west, and is 600 or 700 feet long, the greatest height being 41 feet; but the east end curves round, and extends about 1,000 feet across a low ridge to the northwards. The width of the dam at the top was 50 feet; the upper slope was 2 to 1, and the lower one 2¼ to 1. It was composed of earthwork of excellent material, brought up in layers of about 6 inches, throughly worked together; in the centre there was a wall 3 feet thick, built chiefly of cobble stones laid in hydraulic cement. At the west end of the dam, there was a waste weir 20 feet long, which discharged the surplus water by a channel into the stream below. The discharge-pipes were carried in a culvert, built along the course of the old brook, below the deepest part of the embankment. This culvert was 8 feet wide and 8 feet high in the clear; the side-walls were 5 feet thick, and were carried down 2 feet below the top of the paving, which consisted of 8-inch granite cubes, laid on flagstones, resting upon a bed of about 10 inches of broken stone. The arch was 18 inches thick, covered with a layer of bricks in cement. The side-walls, arch, and granite blocks were set in hydraulic cement of good quality, the side-walls being built double and filled in with concrete. At its inner end this culvert was closed with a masonry, in cement, stopping-piece 10 feet thick, and through it passed the two supply-pipes, 24 inches in diameter. The supply-pipes were governed by a gate-house at the extreme inner end of the culvert; and at the top bank level there was a chamber with roof, floor, door and windows. This inner gate-house appears to have been a substantial structure of stone, lined with brick. At the lower, or outer, end of this culvert there was a smaller gate-house containing the waste gates, and from it extended a stone culvert, to carry the waste water into the stream below. These gate-houses were situated somewhat inside the foot of the slopes, dry rubble wing walls being built to keep off the pressure of the embankment. Before the construction of the dam which failed, there existed a smaller dam, which was covered by the new work. The part of the dam washed out shows that the natural sod was not removed from under this old work, although it was in the new construction.

Particular inquiries were made as to the foundations of the arched culvert and gate-houses. It was ascertained, after the arch was built, and when it was desired to put in the paving, that it could not be done, on account of the softness of the ground; at the upper end of the culvert the ground was wet and springy, and could be shaken by stepping upon it. The paving of the culvert was actually laid by pressing into the soft ground the rough stones before mentioned, and then covering them with the flagstones, upon which the granite blocks were set in cement. A similar difficulty appears to have been experienced with the foundations of the upper, or inner, gate-house, where it was found necessary to press into the moist and springy earth a layer of about 3 feet of broken stone, before the masonry in cement could be commenced. This gate-house, however, does not appear to have settled previous to the giving way of the dam.

The failure of the work was first observed through a leakage of water into the outlet culvert, at a point about 20 feet above the central wall. In April 1875, when the top water was 6 feet below the waste weir, the leakage amounted to 24,221 gallons in twenty-four hours. In July, under a similar head, it had increased to 39,810 gallons per day. On the 7th of September the City Engineer directed attention to the increased leakage; and under date the 1st of December, 1875, he reported that the leakage was then 48,448 gallons per day, showing an increase of upwards of 24,000 gallons since April. His investigations proved that the leakage was confined entirely within a short distance of the upper end. Nothing appears to have been done, either to stop the leak or to empty the reservoir, and when the latter filled up, in the spring of 1876, the leakage increased. Two days before the final giving way of the embankment, muddy water was observed flowing from the waste culvert, and its point of entrance was traced to the old leak. This discharge rapidly increased to more than the waste culvert could carry; when, just before the final failure, the water rose in the lower gate-house, flowing out of the doors and windows. A little before daylight on the 30th of March, 1876, a portion of the dam, about 20 feet long and 5 feet thick, subsided on the west side of the upper gate-house, and between it and the waste weir; the water flowed with a rush and a roar into this hole, and the dam was expected momentarily to break. Bags of hay, stones, and trees were thrown into the breach, so that by daylight the rush of water was lessened. During the day, endeavours were made to relieve the reservoir, by cutting through the embankment at a shallower part. This, however, was not effected till 4 P.M. At 5.50 P.M. the water was seen bubbling up through the earth at the back of the dam. In a few minutes the stream had increased in diameter from an inch to several feet, carrying with it stones and earth. The lower slope was rapidly destroyed; the central wall stood for a second, then burst with a crash, and allowed the reservoir to discharge itself in a solid mass, 20 feet high, through the narrow ravine, 80 feet wide, below the reservoir. The inner gate-house fell over to the south-westwards into the chasm.

The Authors of this report are of opinion that the failure was due to leakage through a porous stratum, of the nature of a quicksand, underlying the upper gate-house and culvert, the water finding its way to some interstices in the masonry of the culvert, until it wore a passage large enough to carry the earth with it, after which destruction proceeded with great rapidity.

The report is accompanied by a letter from Mr. William J. McAlpine, M. Inst. C.E., the engineer charged with the reconstruction of the work, from which it appears that he does not agree with the conclusions of the Committee, but attributes the failure to water having found its way between the earthwork and the central wall of masonry. He says, "Earthen dams rarely fail from any fault in the artificial earthwork, and seldom from any defect in the natural soil—it, the latter, may leak, but not to endanger the dam. In nine-tenths of the cases the dam is breached along the line of the water outlet passages." Again he says, "The outlet passages must be of masonry or of iron, and should rest on and be enveloped in masonry; and extending transversely through the dam is a source of peculiar danger."

The specification for the work of reconstruction is given in the Journal.

A. R. B.

Trial of Pumping Engines for the Waterworks at Lawrence, Mass., U.S.A.

By W. E. Worthen, J. C. Hoadley, and J. P. Davis.

(Journal of the Franklin Institute, vol. lxxii., p. 312.

A pair of compound rotative beam engines, designed by Mr. E. D. Leavitt, Jun., are placed side by side, with a fly-wheel between the engines. The first and second cylinders of each engine are connected one to each end of the beam. They are placed together under the main centre, and consequently are directed obliquely each to its proper end of the beam; and whilst the lower ends of the cylinders are close together, the upper ends lie apart from each other. The connecting-rod to the fly-wheel shaft is connected to the first-cylinder end of the beam, and the rod to the pump to the second-cylinder end. The cylinders are fitted with gridiron valves, having a large area of opening and small movement. The pumps are of the bucket-and-plunger type; but a branch leads from below the foot valves to the under side of the air vessel, which branch is provided with lifting valves, so that the momentum of the suction column may be expended in lifting these valves, and thus passing direct into the air vessel. There are two boilers, similar to locomotive boilers, having each a wide fire-box and a long combustion chamber, with a longitudinal mid-feather, leading to a number of small tubes, within a cylindrical shell. Effective pressure, 90 lbs. per square inch. The cylinders are 18 inches and 38 inches in diameter, with 8 feet of stroke. They are steam-jacketed. The clearances average for the first cylinder 2·43 per cent. and for the second cylinder 1·68 per cent. of the capacity of the cylinders respectively. The volume of the connecting pipe between their upper ends is 9·92 per cent. of that of the first cylinder. The pump barrel is 26⅛ inches, and the plunger 18 inches in diameter, with a stroke of 8 feet. The fly-wheel is 30 feet in diameter, and weighs 16 tons (English). The beams are 16½ feet long between centres. Two 24-inch branch mains from the pumps are joined to a 30-inch force-main 49 feet in length, delivering to the reservoir under a static head of from 165 to 174 feet. The first trial was of a single engine, the second was with the engines coupled, and the head of pressure above the pump was measured by a gauge on the air-chamber; the quantity of water delivered was gauged over a weir at the reservoir.

From the results of the trials reported, it appears that the steam was cut off in the first cylinder at about 30 per cent. of the stroke, with an initial absolute pressure of about 100 lbs. per square inch. The engine made 16¼ turns per minute, and yielded about 195·5 indicator HP. The water delivered per stroke amounted to 95 per cent. of the capacity of the pump. The total coal (Cumberland) consumed was equivalent to 1·69 lb. per indicator HP. per hour, and to 2·06 lbs. per HP. of duty at the pump. The difference of these quantities points to an efficiency of the engine of 81·94 per cent. The duty per 100 lbs. of coal amounted to over 96,000,000 foot-lbs. The average quantity of water evaporated per lb. of coal was 8·27 lbs.; whence it follows that (8·27 × 1·69 =) 14 lbs. of steam, as it came from the boiler, was consumed per indicator HP. per hour.

D. K. C.

Hygienic Studies on the Absorbing Power of Soils.

By Dr. Lissauer.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. viii., p. 569.)

In experiments hitherto carried out in connection with this subject, the samples have been taken by simply digging them from the ground with a spade, a plan which does not permit of the soil being examined in its natural state; and it is clear that its absorbing power mainly depends upon the relative position of the particles of earth to one another. To overcome this difficulty the Author used a tin cylinder, encircled by an iron case made in two halves, so that it might easily be removed, and furnished with a circular steel knife at one extremity and a stout handle at the other. By thrusting this apparatus into the ground, and then withdrawing it by means of the handle, the cylinder could be filled with a sample of soil in its natural condition. By then removing the iron case, and fastening a perforated cap to the lower end of the cylinder, it was possible to filter liquids through the sample without in any way disturbing it.

The results of fifty-one experiments made with this apparatus point to the following conclusions:—

1. The liquid entering the pores of the soil displaces the air or liquid previously present, forcing the former upwards into the atmosphere, and the latter downwards into the subsoil or effluent water.

2. In order that the effluent water may not be directly polluted by the sewage liquid, the maximum supply of the latter must not be more than can be taken up by the pores of the soil.

3. Dry loamy soil absorbs more than peaty soil, and gives up less, whilst dry sandy soil, on the contrary, absorbs less and gives up more. Consequently a loamy soil, though it absorb a large quantity of liquid, can seldom be irrigated; whereas a sandy soil, though it absorb but little, may often be irrigated.

4. The looser the soil the easier water-courses are formed in it, and therefore the less can its maximum power of absorption be approached, otherwise the sewage liquid might penetrate the subsoil before the whole of the ground had been saturated.

5. In order, therefore, that the effluent water may be protected from pollution, it is especially necessary that the absorptive power of the soil should be known; but the determination is of no value unless it be made in a sample in which the natural position of the particles of earth has been undisturbed.

6. Having determined how much fluid a cubic yard of the soil can take up, and therefore how much is necessary for the daily supply of sewage liquid, this is to be multiplied by the number of days which must elapse before the organic matters present in the liquid shall have been destroyed. As a criterion of this, it is sufficient to ascertain if, after all free ammonia has been expelled, any more is formed on burning with soda-lime; but in making use of this test of course any nitrates or nitrites that may be present must be taken into account. This period of time should be determined by special experiments at different times of the year and under different systems of cultivation.

7. The presence of such non-nitrogenous organic acids as arise from regressive metamorphosis cannot serve as an indication of the impurity of the effluent liquid, since, when once formed, they remain unchanged for a long time.

8. Having determined the cubic amount of earth which is necessary for the available supply of sewage liquid, some means must be taken to guard against the fluctuations of the effluent water by drainage. It is therefore recommended to add at least ½ yard to the depth as reserve soil, for the protection of the effluent water from such accidental disturbances as rain or the formation of water-courses.

9. Suspended matters only then pass through the soil when, like Bacteria and Monads, they are smaller than its interstices and specifically lighter than the sewage liquid.

10. The suspended matters which are specifically heavier than the sewage liquid are retained by the soil, making it closer and increasing its power of absorption.

11. The absorptive power of a soil depends upon its character, and also to a great extent upon the degree of concentration of the liquid used. Unless, therefore, the determinations are made with solutions of equal strength, they lead to false conclusions.

12. As the result of four years' irrigation at Heubude, the absorptive power of the soil has been more than doubled.

13. The absorptive power of a soil for urea is very much increased by vegetation; but however high it may be, the soil never withdraws the whole of the urea from a liquid; some of it always remains in solution.

14. The effluent water of irrigation works ought not to be compared with good drinking water, since it must nearly always contain some ammonia, often nitrates and nitrites, and always a certain amount of chlorine, which is almost completely unabsorbed by the soil.

H. H. B. S.

Artesian Wells in Spain.

(La Gaceta industrial, No. 20, 1876.)

The sinking of artesian wells in the provinces of Murcia and Valencia has been recently attended with great success, between seventy and eighty having been sunk since the year 1869. At Carthagena two had been opened at an earlier date, under the direction of the naval authorities, and the more recent success which has rewarded private enterprise is due to two intelligent workmen there employed, who now act as the managing directors of two companies. Their experience enables them to determine with tolerable accuracy where water will be found, and they rarely fail to meet with it at depths varying from 25 to 70 yards, in a part of the province of Murcia which has an area of about 185 square miles. The deepest well in that district is 90 yards, and the cost of sinking does not usually exceed £200. The wells are lined with iron tubes, 5 inches in diameter, and the water is thrown up to a height of from 2 to 3 yards above the surface. A good well will supply sufficient water for the daily irrigation of about 8 acres, and under the burning sun of those provinces the profit derivable from them is immense; the arid parched soil being at once converted into productive vegetable gardens. The geological formation, identical throughout the whole district, consists, on the surface, of a bed of clay between 6 and 7 yards in thickness, below which lie alternate beds of sand, clay and gravel.

It was not until after many of these wells had been successfully sunk in the province of Murcia that it was determined in August 1876 to try whether they could be established in Valencia. A large tract of land about 2 leagues from the capital had been unsuccessfully irrigated by means of norias or water-wheels, as the quantity of water near the surface was limited. The soil, on boring, proved to be similar to that of the Murcian district, and to contain water at about the same depth, the first well having thrown up an abundant supply on reaching a depth of 55 yards. Great importance is attributed to the subject by the neighbouring landowners, as water for irrigation has an exceptionally high value in Murcia and Valencia, where the rainfall is extremely limited.

O. C. D. R.

An Artesian Well at Rank-Herlány, in Hungary.

By B. Zsigmondy.

(Berg- und hüttenmännische Zeitung, vol. xxxv., p. 277.)

The mineral springs of Rank-Herlány, situated about 14 miles N.E. of Kaschau, in Upper Hungary, have of late years attracted a considerable number of summer visitors; and the supply of water from the natural springs being insufficient to meet the requirements of the bathers, it was determined, in 1870, to sink an artesian well to tap the carbonated water in depth. As geological researches showed that there was water under the whole district, the spot chosen for the well was the one most convenient to the baths. The work of boring commenced on the 5th of June, 1870, and had reached a depth of 364 feet by the 4th of January, 1871, when the water, mixed with gas-bubbles, began to flow slightly, increasing gradually to 7 pints per minute by the 28th of March. After much labour, entirely manual, at a depth of 564 feet, the water suddenly rose to 13 feet above ground-level, and 17 feet above the tube, for about five minutes, when it suddenly sank again out of sight. These spasmodic eruptions continued several times daily up to the 4th of July, 1873, when, with a depth of 902 feet, the first great rush of water took place. As the house covering the well was closed at the time, no accurate observation of the phenomenon was possible, beyond the fact that, in spite of numerous obstacles, the water tore off the roof, which was 65 feet above the ground-level, rose to a further height of 20 feet, and then subsided. On the 17th of December of the same year, a similar eruption occurred, and was repeated continually during the further progress of the works. On the 5th of October, 1874, at midnight, with a depth of 1,082 feet, a stronger vein was tapped. The water at first rose to 39 feet for two or three minutes, and then again sank in the pipe for one or two minutes, to rise again with the same force. Owing to these continuous eruptions the work was attended with great difficulty, as the men were not only subjected to blows in the face from the water, but were at times obliged to escape from the irrespirable gases which rose with it. On the 9th of October the flow stopped for four hours, and the intervals of eruption became daily less frequent, and the pauses between each of longer duration.

At a depth of 1,326 feet the work was stopped, chiefly on account of the fall of ground from the sides, which became dangerous and threatened to block up the rods in the hole; to go to a greater depth it would have been necessary, therefore, to obtain fresh lining tubes, which would not only have increased the expenditure, already very considerable, but would have postponed the completion of the works for controlling and utilising the spring. The supply was in fact more than sufficient for the wants of the establishment, and a great part of the water ran to waste in the brook.

The section of strata is as follows:—

			Feet.
1.	Diluvium	to a depth of	15·4
2.	Grey soft clayey sandstone	"	25·3
3.	Grey clay	"	65·6
4.	Grey fine-grained soft sandstone	"	78·7
5.	Grey clay, with black streaks	"	98·4
6.	White and grey trachytic tuff, with alternations of clay	"	465·7
7.	Sandstone, with white tufaceous cement	"	567·5
8.	Grey sand	"	574·5
9.	Grey clay, with sandstone layers	"	639·5
10.	Grey plastic clay	"	652·8
11.	White, yellowish, and grey sandstone, coarse and fine	"	866·0
12.	White and yellow sand, and sandstone	"	902·0
13.	Clayey sandstone, with hard layers of clay	"	1,038·0
14.	Very hard grey sandstone	"	1,096·5
15.	Grey and white trachytic tuff	"	1,190·5
16.	Very hard grey sandstone	"	1,259·0
17.	Grey plastic clay	"	1,300·0
18.	White fine-grained clayey sandstone	"	1,310·0
19.	Grey sandy clay	"	1,457·0

The well was lined to a depth, from the top, of 1,152 feet, the lowest pipe having a diameter inside of 4 inches. The results of a partial analysis of the first water obtained gave 2·144 parts of solids to every 1,000 parts of fluid, consisting of carbonate of potash, carbonate of iron, carbonate of soda, chloride of sodium, and carbonate of lime, or 0·0117 part of carbonate of iron, 0·3560 part of carbonate of lime, and the remaining portions, 2·144, consisting principally of carbonate and chloride of sodium. The quantity examined, however, was too small to allow of a complete analysis, and no determination of the amount of gas given off has been made.

The water continues to flow with intermittent eruptions, commencing with a height of 82 to 100 feet, with innumerable pulsations, gradually receding to 32 or 48 feet, when the pulsations can be counted, and, after about fifty minutes it subsides with spasmodic jets, sinking at last back into the tube to a depth of

100 to 160 feet. The noise of the seething water is heard for hours; when at last it ceases, the spring is for a short time at rest, then begins gradually to rise, and at last spouts forth again in the manner described. The intervals between the outflows are from eighteen to twenty hours, the duration of the outflows about two and a quarter hours in every twenty-four. The quantity of water delivered varies during the periods of outflow, being, during the first, 7,000 gallons, during the second, 4,690 gallons, and during the third, 2,344 gallons, or an average of about 4,700 gallons per minute, or during two and a quarter hours, 10,600 gallons. The temperature varies with the outflow from 59° to 62° Fahr. at first, to 73° or 75° at last. The quantity of carbonic acid gas has not been determined, but it is considerably greater than the volume of water.

W. E. T.

On the Production of Ammoniacal Salts from Sewage Liquids.

By L. KRAFFT.

(Revue universelle des Mines, vol. xl., p. 43.)

The Author, in conjunction with M. Sucquet, devised a plan for the disinfection of the contents of cesspools by the application of precipitated hydrated ferrous oxide, which was obtained by decomposing green vitriol with ammonia, produced from the sewage liquids (*eaux vannes*) by distillation. These liquids may be considered as containing two principal constituents, namely, carbonate of ammonia and sulphuretted hydrogen, which, by mutual decomposition, produce sulphide of ammonium, an extremely volatile and fœtid gas. By the addition of ferrous oxide, however, the sulphuretted hydrogen is destroyed, water and sulphide of iron being produced, the latter a perfectly inert substance and without disagreeable properties. A process based upon these reactions was used in a manufactory at Carlebourg, near Paris, the ammoniacal water being concentrated by distillation by three different methods. The first experimental still was a wagon boiler, fired underneath and provided with an agitator, moved by steam power, for stirring up the contents. About 300 gallons of liquid, previously treated with lime to decompose the carbonate of ammonia, were charged at each operation. The ammoniacal gas given off was received in a solution of ferrous sulphate with the production of sulphate of ammonia, and an abundant precipitate of hydrated ferrous oxide, which was separated by filtration through cloth, or allowed to settle in tanks, and afterwards used as a disinfector. Each operation lasted from an hour and a half to two hours, and required about 2¾ bushels of coal. Under these conditions—due chiefly to imperfections in the apparatus—it was found that the cost of operation could not be covered by the ammoniacal salt produced, so as to obtain the disinfecting iron oxides free of charge, as was desired. By the use of an improved distillatory apparatus on Laugier's construction the yield was considerably increased, the time of working and the consumption of coal being correspondingly reduced, so that a notable profit was realised. This was owing to the more complete utilisation of the heat, the whole of the liquors being heated 50°, or at times 70° cent., before being admitted to the still. As the ammoniacal liquors were at from 15 to 19 alkalimeter degrees of concentration, the decomposition of the iron salt could be effected in a strong solution, so that less water had to be evaporated to obtain crystals of sulphate of ammonia than in the former case. The same amount of fuel which was required to distil 1,540 gallons containing 227 lbs. of sulphate of ammonia in the first still sufficed, in the Laugier apparatus, for working 3,960 gallons, giving 470 lbs. of sulphate.

As regards the actual proportion of ammonia recovered, it was found that ten charges containing ammonia equal to 353 lbs. of sulphate gave—

	lbs.
145 gallons of ammonia water yielding 1·8 lb. per gallon (180 grammes of sulphate per litre), or in all	261
The spent liquors contained	79
	340
Leaving as lost by volatilisation and errors of observation	13
	353

The average consumption of coal was about 1 bushel per 118 gallons ($\frac{1}{2}$ hectolitre per cubic mètre). Another modification of the second method was tried, in which the still was heated by high-pressure steam instead of by direct firing, but the results were not satisfactory, as the consumption of fuel was the same, and although the operation was more rapidly conducted, the spent liquids contained a much larger quantity of ammonia, up to nearly half the original contents. The results of four groups of experiments gave a loss of 38 and 42 per cent. with steam heating, and 25 and 19 per cent. with direct heating. Another method, intended for the treatment of the sewage of towns, was that by ventilation. The liquid, having been previously treated with lime and clarified, was exposed for varying periods to the action of a current of air from a fan-blower. In the first instance the ammoniacal liquor was at rest in a long narrow covered trough, but subsequently the plan was varied, by allowing it to flow through the trough in a thin stream in a direction contrary to the air-current, in order to obtain the greatest possible number of points of contact between the two fluids. The air, loaded with ammonia vapour, was passed through a condenser tower containing fragments of glass and porcelain, kept constantly wetted with sulphuric acid. When discharged, it showed no alkaline reaction with test paper, a proof that the whole of its ammonia had been converted into sulphate.

The experiment was modified in a great number of ways, full details of which are given, with a view of obtaining a method practicable on the large scale. These modifications were chiefly in the method of distributing the liquid current. The plan finally adopted was an underground basin through which the liquid passed in a layer from $\frac{2}{5}$ to $\frac{3}{5}$ inch deep, the current being broken by overfalls at intervals of 30 feet. The time occupied by the liquid in passing through the basin was from twenty-two to twenty-five minutes. The best results were obtained with from 80 to 100 gallons passing through per hour and forty revolutions of the ventilating fan per minute, when about one-half of the total amount of ammonia was removed. The fan used was one from an ordinary smith's forge, and was estimated at 1½ HP. at most; the consumption of coal in twenty-four hours was from 3 to 4 hectolitres (7 to 9 cwt.), corresponding to between 5,500 and 6,500 gallons of liquid treated. The Author suggests a more expeditious method of working the process by substituting a cascade tower filled with blocks of sandstone for the covered trough, as by such an apparatus two-thirds to five-sixths of the total amount of ammonia was removed by once passing the tower.

The partially "ventilated" liquor was subsequently passed by a covered conduit into a long open trough divided at intervals by walls so as to form a series of basins. At the upper end of the trough was placed a barrel filled with water, in which a basket containing crystals of sulphate of iron was suspended in order to obtain a solution of constant strength. It was allowed to trickle in drops into the effluent stream from the tanks, whereby the residual ammonia was fixed and the oxide of iron resulting from the decomposition was deposited in a paste form in the settling basins. When it had become sufficiently compact to be dug out with spades, it was used as a disinfectant when removing the contents of cesspools.

The method described by the Author was proposed for use in Paris, but, although favourably reported upon, has not as yet been adopted.

H. B.

Production of Gas from Waste of Cloth Manufactories.

By E. SCHWAMBORN.

(Journal de l'Éclairage au Gaz, vol. xxiv., p. 166.)

The German Government recently appointed Messrs. Landolt and Stahlschmidt[1] (professors at the Aix-la-Chapelle Polytechnic School) to report on the means used in Belgium and Germany for rendering waste water from factories innocuous. Filtration by gravel or ashes, although removing mechanically suspended matter, fails to eliminate soapy impurities. The Author sets aside methods for retaining the fatty matter by means of acids, as these do not clarify the water, and considers only those which deal with lime treatment of the waste water.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 320.

Waste from fulling factories contains oil (used in spinning) to the extent of 15 per cent. of the weight of the thread, and soap (used in fulling), the proportion of which rises to 30 per cent. of the weight of the cloth, leaving out of account the size and colouring matter.

The purifying apparatus consists of a channel conveying the dirty water from the fulling or washing machine to a reservoir, in which all solid matter in suspension is allowed to settle. This reservoir contains about 33,000 gallons, and would be filled in about a fortnight, assuming at the same time a consumption of 1 ton of soap, equivalent to the treatment of 4 tons of raw material. At the bottom of the reservoir there is a channel by which the contents are drawn to a precipitating reservoir, situated at a lower level. Into this channel is discharged, from a tank above it, a jet of milk of lime, regulated by a tap. The bottom of the precipitating reservoir is formed of three courses of bricks, so arranged as to allow the drainage-water to escape, and it is sloped towards one corner, in which is placed a funnel perforated with a series of holes, so that the surface-water can be gradually drawn off by opening these holes, first at a higher and then at a lower level. Precipitation takes place as soon as the waste water, saturated with lime, reaches the precipitating reservoir, and the amount of saturation may be estimated by the fleecy appearance of the surface-water. Roughly, it may be assumed that 3·1 tons of milk of lime will purify 150 tons (33,000 gallons) of waste water. Calcareous soap is deposited, the clear water is gradually drawn off, and the solid matter dried by being spread out on the ground and exposed to the air.

Statistics show that the weight of fulled material annually reaches the amount of 500,000 tons in Europe, and all the cloth works, using some 125,000 tons of soap, could produce 100,000 tons of calcareous soap by the above process, to which must be added 50,000 tons of oil used in spinning. In order to determine how far this substance may be employed for making gas, either by itself or mixed with coal, experiments were carried out in the winter of 1875–76, during twenty-two evenings, by M. Desclabissac and the Author. The materials used were gas coal of the "Consolidation" seam at Gelsenkirchen, fatty matter obtained from wool washings, stearine (*goudron de stéarine*), and calcareous soap. The illuminating power of the gas was estimated by a Bunsen photometer in a room hung with black. The standard was an English spermaceti candle of normal size. The charges put into the retorts consisted, for the first five evenings, of 117 lbs. of soap and 708 lbs. of coal, producing 2,800 cubic feet of gas, or 340 cubic feet per 100 lbs. of charge; the lighting power, with a consumption of 2½ feet per hour, varied from 25⅙ candles at the commencement, to 14⅓ afterwards.

The light given for equal consumption of different materials was as follows:—

	Coal.	Grease.	Stearine Tar.	Calcareous Soap.
Candles	9	27·5	29·3	32·3

For equal weights the quantity of gas produced by calcareous soap and coal is as 1·61 to 1; and as the illuminating power of the gas produced is as 3·59 to 1, the total advantage in light of the gas produced by calcareous soap will be as 5·78 is to 1, or 100 lbs. of calcareous soap will give as much light as 578 lbs. of gas coal of the best quality. The cost of 578 lbs. of coal at 21*s.* per ton would be 5*s.* 3*d.*; of this 60 per cent. would remain as coke after distillation; and of this again ⅔ or 40 per cent. would be required for the fresh charge, leaving a saleable production per 100 lbs. of 20 lbs. of gas coke. Calcareous soap, owing to the facility with which the gas is given off, requires 25 per cent. less coke for distillation; 100 lbs. of calcareous soap, therefore, only require 30 lbs. of coke, at a cost of 2*d.*, the price of fuel being put at 12*s.* the ton. The soap may also be mixed with coal to produce coke for heating the retorts. A charge of 116 lbs. of calcareous soap, at 5*s.* 6*d.* for 100 lbs. (cost of equivalent of coal), and 708 lbs. of coal, at 21*s.* per ton, will afford the necessary amount of coke, and will produce 2,716 cubic feet of gas, with an illuminating power of 9 candles per 2½ cubic feet burnt per hour. Thus, while calcareous soap is only $\frac{1}{7}$ of the charge with equal weight, the mixture would give an advantage over coal of 1·68 to 1. Owing to the facility with which calcareous soap is distilled, smaller retorts and less plant are necessary for the production of the same amount of light-giving power.

J. J. T.

The Velocity of Propagation of Waves. By M. LAROCHE.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 741.)

Suppose a slight uniform discharge to take place from a channel rectangular in section, with a horizontal bottom, and of indefinite length, then, according to the experiments of M. Bazin, a thin layer of water will slide along the surface of the water in the channel. Let H be the depth of the water, h the thickness of the layer. If the front, n', of the slight undulation $n\,n'$ advances to n'' with a velocity V, the whole mass of water between n' and n'', throughout its whole depth, will have a velocity such that $u\,(H + h) = V\,h$. All the molecules in any given section A B, at some distance above n', have the same horizontal velocity u, and in an infinitesimal space of time, $d\,t$, these molecules will have advanced into another section A′ B′, the distance between the two sections being $u\,d\,t$. In the same period, dt, the front, n', of the undulation will have travelled to n'' with a velocity V, so that $n'\,n'' = V\,dt$, also $(H+h)\,u\,dt = h\,V\,dt$. Suppose the channel closed by another sectional plane, C D, lower down than the limit of movement during a time dt, and kept in place by a force equal and opposite to the pressure above, the amount of motion, M, between A B and C D at the commencement of the time dt, becomes M′ between A′ B′ and C D at the end of the time. $M - M' = m - m'$, where m is the amount of motion of the molecules between $n'\,n'_1$, $n''\,n''_1$, and m' the amount between A B and A′B′, and

$$m - m' = \frac{a}{g}\,dt\,h\,V^2\left(1 - \frac{h}{H+h}\right),$$

where a is the specific gravity of the liquid. This amount of motion must equal the impulse of the three forces acting during the time dt. One force is that exerted in making the section A B advance to A′ B′, which, owing to the slow flow and absence of agitation of the water, may be considered equal to the hydrostatic pressure $(H+h)\,\frac{H+h}{2}\,a$. Another force keeps the section C D in place, namely, the pressure $H\,\frac{H}{2}\,a$. Lastly, there is a force which pushes forward the front of the undulation, and may be considered equal to a hydrostatic pressure $h\,\frac{h}{2}\,a$. Combining these forces, their impulse is $a\,h\,(H+h)\,dt$, which being equal to $m - m'$, gives

$$V^2 = g\,(H+h)\,\frac{1}{1 - \frac{h}{H+h}},$$

and when $\frac{h}{H+h}$ may be neglected, it becomes

$$V^2 = g\,(H+h), \text{ or since } h \text{ is very small, } V^2 = g\,H.$$

L. V. H.

The Movement of the Sea, viewed in its Hydraulic Relation to Ports and Shores. By A. CIALDI.

(Rivista marittima, vol. ix., p. 50.)

In the autumn of 1873 the Royal Venetian Institute of Science, Letters, and Art offered a prize of 3,000 lire for the best essay on the movements of the waves and littoral currents. The competitors were invited to discuss the most accredited theories, and, with observations of recognised phenomena, to deduce a more complete theory, especially with reference to the compound action of waves and currents on the change of coast lines, and on the efficacy of maritime constructions; such as might tend to the improvement and preservation of ports and shores, especially those of Italy. The essays might be written in either Italian, Latin, French, German, or English. Signor Cialdi had, in the "Rivista marittima" for 1874, given his "Preliminary Notions as to a Treatise on the Construction of Ports in the Mediterranean," the second chapter of which, treating of winds, waves, and currents, which he regarded as the most important, had been much controverted in Italy. The invitation of the Venetian Institute induced him to appear as an anonymous competitor; citing his own former works, as well as those of his opponents.

The essay, which was the only one presented, although greatly praised for its elaborate learning, was not thought to fulfil sufficiently the conditions of the Institute, and did not receive the prize. It is divided into three parts, each headed by a distinct paragraph of the programme given by the Venetian Institute. The first part contains two articles,—on the accredited theories of the movement of liquid molecules in the formation or development of marine waves; and on tidal and littoral currents. The former article commences by the definition of certain terms, and then refers to the theory of Newton on the velocity of waves, and to that of Gerstner and the brothers Weber, published in 1825, on the orbital movement of the liquid molecules in waves. Mr. Merrifield's "Summary of the Theory of the Oscillating Sea Waves" is also cited. Signor Cialdi concludes this portion of his work by expressing the opinion that he has demonstrated that the theories hitherto produced, in order to explain the motions of the sea by means of mathematical analysis, are not of much use with reference to the questions of the construction of harbours, or the advance or retreat of the shore.

In the second section, Signor Cialdi asserts that the tidal wave attains, in the high seas, a velocity of not less than 2 miles per hour; which rises to 6, or even to 10 miles per hour, according to the obstacles which it encounters on the shores. He holds that in the same degree that these obstacles diminish the velocity of the propagation of the wave, they augment its transporting power, and cites experiments made in France and in England, to show that, at a velocity of 6 inches per second, water transports soft clay; at one of 12 inches per second, it transports ordinary sand; and at that of 38 inches per second, it transports pebbles as large as a hen's egg. The transporting power of the sea-water he takes to be higher than the above, inasmuch as its density is $\frac{1}{40}$ more than that of fresh water. In calm weather the tide wave on the Italian coasts remains limpid. In stormy weather the Author considers that the turbid matter which it contains is removed in the same manner in which it is brought by the tidal current; so that the tides of the Mediterranean have not a sensible action on the shores of Italy.

He then discusses the "Mediterranean current," known as the littoral or "grazing" (*radente*) current, which flows from the right hand to the left of the observer who faces the sea; and which attains in the Adriatic a velocity of 3 or 4 miles in the twenty-four hours; and in the rest of the Mediterranean, on the average, a velocity of 8 miles in the same space of time. He gives an observation of his own, made from a small steamer anchored near Corneto, in 12½-foot depth of water (on the 4th of August, 1857), of the bottom of the sea, where he saw the marine algæ bending, perpendicularly to the shore, from west to east, showing the direction of the gentle current at the spot. As the tops of these seaweeds were about 8½ feet below the surface, he concludes that the littoral current was unfelt at that slight depth, and that the littoral current has little or no transporting power. His investigations are limited to the Adriatic, as that sea has been chiefly studied by Montanari and his followers; and holds that the laws which regulate the accretion of shores must be the same on all the coasts of the world. He then discusses the prevailing winds on the Adriatic, and concludes this section with a note to the effect that it is to be regretted that the littoral currents have been rather sought for in maps and books than measured in the sea itself.

The second part of the treatise discusses first the materials which become obstructions on shores, and then what the Author calls the "garland of adventitious deposits." This region, which D'Archiac has called the "zone of sanding-up" (*atterrissements*), extends, according to Signor Cialdi, from the coast line to a depth of 328 yards in the ocean, of 164 yards in the Mediterranean, and of 87½ yards in the Adriatic and in the English Channel; he says that the waves of the sea have a visible transporting power to a depth of 218 yards in the ocean, of 54½ yards in the Mediterranean, and of 44 yards in the Adriatic and the Channel. The materials deposited in this zone he regards as derived, first, from the deposits brought down by rivers; secondly, from the erosion of portions of the sea coast; and thirdly, from the productions of the sea itself; that is to say, from the remains of marine plants and animals. Entering at considerable length into recent works on the natural history of marine life, he concludes that the deposits on the shores of the Italian seas are formed, in the Mediterranean, by 30 per cent. from river deposit, 20 per cent. from erosion of shores, and 50 per cent. from organic bodies; and in the Adriatic, by 35 per cent. of the first, 5 per cent. of the second, and 60 per cent. of the third.

The second section of this part of the essay proposes to establish a complete theory as to the compound action of the waves and currents in altering the coast line, and affecting marine works. It speaks of the depth to which the movements of the waves is felt, and of the submarine current which the Author holds that they generate. It mentions the effect of the wind, in raising the waters on the shore above their mean level by about 19 inches in the Tuscan Sea, 3¼ feet in the Adriatic, and 6½ feet in the ocean. It refers to the report of the International Commission on the Bay of Pelusium, and to the westward current there prevailing, which flows in an opposite direction to the assumed littoral Mediterranean current. It refers to the action of the dominant winds upon the waves, the phenomena of which he discusses at considerable length.

In the third part the Author treats first of the hydraulic works carried out, especially on the western and southern shores of the Adriatic, the experience derived from which confirms, in Signor Cialdi's opinion, the theory of the wave current. He refers to the deposits of the Po and of the Adige, and to the changes in the *foci*, or openings through which the waters of these rivers finally join the Adriatic, that are due to the variation of the winds.

The second section of this part discusses the subject of such harbours as Signor Cialdi calls port-basins. He concludes that when such a harbour (of which Ancona furnishes an example) has only one mouth or entrance, this must always be placed on the leeward side, or away from the dominant winds. He refers to the actual and the prospective increase in the size of vessels, especially steamers; and to inconveniences in the ports of Naples and of Genoa in consequence of their being open to the prevailing winds.

In the third section Signor Cialdi treats of what he calls canal-ports, which he says are always formed on level, and therefore either sandy or gravelly shores; and are on that account very difficult to maintain. The convenience of navigation demands that such ports should either be at the mouth of a river, at that of a lagoon receiving the tidal water of the sea, or joined by an artificial canal. The essential feature of these ports he takes to be the construction of two parallel jetties, or 'guardian moles,' leading to the sea. He cites the area of the lagoon of Malamocco (which is 40,200 acres), and the width of the canal between the jetties (which is 515 yards), as an example capable of general application under the second division; the Sulina mouth of the Danube being a case of the first kind. The third case, that of the purely artificial canal, is illustrated by the entrance to Port Said. As to this, Signor Cialdi cites the report of Colonel Stokes, R.E., to the effect that the repeated extension of the pier seems to be a hopeless feature in the method of dealing with the difficulty of the constant deposit of material in the bay; a deposit which is computed by that officer to have amounted to more than 5,000,000 cubic yards within three years.

In the fourth section of this part of the treatise, Signor Cialdi proposes his own method of meeting the difficulty of a canal-port. Instead of two parallel jetties, he proposes to make the leeward jetty much shorter than at present is usual; and to cut the windward jetty into two parts, by an opening about the spot where the bar is generally formed. The jetties should be built with a slightly curved plan, with the convexity opposed to the prevailing wind. At the end of the first part of the longer jetty (where the opening is made) the sea wall is returned to the windward at right angles or thereabouts. It is anticipated by Signor Cialdi that the action of the wave current, deflected by this return, will keep free the opening between the two parts of the main or windward jetty, and thus maintain a free entrance to the harbour.

The work concludes with a summary of the arguments adduced to show that the theory of the wave current is that which explains the action of the sea on the shore, and is alone applicable to the improvement of ports or the preservation of coast lines.[1]

F. R. C.

The Erection of Cofferdams on Rocky Ground at Pola.

By J. PRUCHA.

(Stummer's Ingenieur, vol. v., p. 38.)

The building slips of the Austro-Hungarian harbour and naval arsenal at Pola extend about 150 feet into the sea, at a maximum depth of 21 feet below low water. In building them it was necessary to inclose the spot by cofferdams. The inclination of the ground reaches a depth of 33 feet below low water at the end of the slip. The hard rock was covered with mud and pebbles to the height of only 2 to 3 feet, which had to be removed by dredgers to obtain a good foundation for a dam of so-called "terra d'Istria," or "red earth," a loamy humus containing iron, which, for its watertightness, is much prized for building.

The dam was formed by tipping the earth into the sea, till it reached high-water mark at the coast-wall, and, following the slope of the ground, was at its lowest point, 13 feet below low-water mark. The height of this dam was about 6½ feet, the breadth of the crown 32 feet, with slopes of 1 in 2.

Upon this foundation the cofferdam was constructed of two double rows of sheet piling 19 feet apart, leaving an inner space of 52 feet for the building of the slip. The plan of the head was polygon-shaped, and formed of piles 10 to 12 inches wide, the double walls at that part being about 26 feet apart. At the shore end, the side-dams joined the quay-walls, previously erected. Two longitudinal baulks, 12 to 15½ inches wide, kept apart by vertical struts, strengthened the piling on the outside. The upper longitudinal was applied at low-water level, the lower one at about 3 feet 3 inches above the crown of the earth-dam.

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[1] For definite information as to currents in various parts of the Mediterranean and as to the deposits brought down by the affluent rivers, the student is referred to "Investigations of the Gibraltar Strait Current," contained in a Report from Capt. Nares, H.M.S. *Shearwater*, to Rear-Admiral Richards, C.B., F.R.S., Hydrographer of the Navy, dated October 1871; to a "Report on the Currents of the Dardanelles and Bosphorus," by W. J. S. Wharton, Commander of H.M.S. *Shearwater*, to the Hydrographer of the Admiralty, dated 31st December, 1872; and to "An Inquiry into the Soundness of M. de Lesseps' Reasonings and Arguments on the Practicability of the Suez Canal," by Capt. Spratt, R.N., C.B., F.R.S., printed by the Queen's Printer in 1858.—F. R. C.

A scaffolding, formed of 13½-inch planks, ran along the whole work. The height of the cofferdam was 8 feet above low water; it was filled with clay firmly punned. The surface of the filling sloped down towards the centre, its height being 8 feet above low water at the outer, and 12 inches below the inner pile-sheeting. After the spot had been closed in from three sides, a strut framework was erected, to strengthen the cofferdam against external pressure.

A stationary engine of 8 HP. removed the water from the building ground by a double-acting pump of 1 foot diameter. Two more strut frames were put in afterwards. The whole material used for this cofferdam (including the red earth) was subsequently removed to the site of the second building slip.

The extensive dry docks at Pola were inclosed in a similar manner during building, although here the rocky ground lies in a greater depth below water-level. The cofferdam was in this case formed of three sets of sheet piling, rammed in 13 feet apart; the piles being 14 to 17 inches wide. The two outer rows formed a polygon, while the plan of the inner one was segmental. Tie-rods were put in alternately between the middle and outer and between the inner and outer sheet piling. The dam had a width of 39 feet 3 inches at the crown, and its lowest point was 14 feet 9 inches below low-water mark.

L. E.

The Mississippi Jetties. By JAMES B. EADS, M. Inst. C.E.

(New Orleans Times, August 11, 1876.)

Since the last report, the depths of the channel between the jetties have been constantly increasing, and, with the exception of a few hundred feet at the sea ends, they are above mean level of low tide, and for the greater part of their length reach to the level of average high tide. The willow mattresses now constructed will be ultimately consolidated by a layer of stones, in order to prevent the escape of water through the top courses. This escape becomes greater towards the sea ends, and the jetties being parallel, the scouring is less marked in the lower than in the upper part of the channel. As a temporary measure for the correction of this, wing dams, 150 feet in length, have been thrown out at short intervals towards the channel, for a length of ½ mile at the sea end of the jetties. The surface width has thus been reduced at the lower ends to 700 feet. The wide and deep passage already created above this contracted portion proves the ability of the stream to maintain a channel 1,000 feet wide throughout the entire length of the jetties, as soon as they shall be so far completed as to control the current and prevent the escape referred to. The survey of the 27th of July, 1876, shows a channel of 2¼ miles from the upper end of the jetties to within 250 feet of the deep waters of the Gulf, having a general width of 350 feet, the average soundings being over 26 feet, while the least were 20 feet and many were over 40 feet. The progress of the erosion between the jetties had, in forty days, increased, to an average width of nearly 100 feet, the 20-feet channel existing on the 17th of June. On the 14th of August a straight channel 21 feet deep was available through the bar, and had so widened that a 20-feet channel, whose minimum width was 140 feet, extended entirely across it.[1]

The prevalent idea that rakes or scrapers had been used with advantage in deepening the channel was erroneous. Some slight improvement seemed to follow the use of the first weak and crude machines of the sort. This had prompted the construction of a strong barrow and scraper combined, which was dragged over the bar continuously for several days by a powerful tug in a depth of between 15 and 16 feet, but it proved to be useless and was abandoned. The only place where any good results were observed was at a point about 3,000 feet above the outer ends of the jetties, where the deepening by the current was only 3 feet between the 4th of March and the 1st of May. This was probably owing to some clay or mud-lump deposit which yielded but slowly to the action of the current. The barrow was gauged at 19 feet by suspending chains from the tow-boat, and being worked at this place an increased depth of 1 foot or 2 feet was obtained. Since its disuse, however, the channel has deepened here to the extent of 6 or 8 feet.

F. G. D.

Theory of the Elasticity and Strength of Hollow Cylindrical Bodies.

By G. Kaiser, Professor at the Higher School of Artillery, Vienna.

(Mittheilungen über Gegenstände des Artillerie- und Geniewesens, 1876, p. 413.)

Before considering the strength and elasticity of hollow cylinders, the Author investigates the effect of strains upon rectangular prisms, and the alteration in form caused by them. He applies the results thus found to hollow cylinders acted upon by forces, by cutting them into a number of small approximately rectangular prisms; and for hollow cylinders open at both ends, and exposed to internal pressure only, he finds that the greatest difference between the internal force and the tangential strain on any element takes place at the inside of the cylinder. This difference decreases towards the outside of the cylinder, and becomes nil at the outside.

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[1] In a letter dated October 4, 1876, Mr. G. W. R. Bayley, the Resident Engineer, states that subsequent soundings give 22·2 feet as the least depth at average flood tide across the outer bar between the jetties.—Sec. Inst. C.E.

If the cylinder is to resist the internal force P_i, the working strain J of the material must not be exceeded at any point of the cylinder; and since the particles on the inner surface of the cylinder are subjected to the greatest strain in the tangential direction, this strain should equal the working strain of the material.

From this the thickness of metal is found to be

$$r_i \left[\sqrt{\frac{3J + 2P_i}{3J - 4P_i}} - 1 \right]$$

As this equation gives an infinitely great thickness of metal for $P_i = \frac{3}{4} J$, P_i must always be smaller than $\frac{3}{4} J$.

As regards the real resistance of a cylinder, and the ideal resistance (in which all the concentric layers of the cylinder are supposed to take equal part in resisting the internal pressure, which in reality they do not), it has been found that the proportion between them decreases as the thickness of metal increases, and that it is of no advantage to make the thickness of metal more than one diameter of the bore. For instance: hollow cylinders of a thickness of metal equal to the diameter of their bore, are capable of resisting an internal pressure equal to 63 per cent. of the working strain; if the thickness of metal is increased to 1½ time the diameter of the bore, the strain resisted only increases by 5 per cent.; and if the thickness of metal is increased to twice the diameter of the bore, the strain resisted is only increased by 2 per cent.

It will be seen from the above that it is impossible to construct hollow cylinders to resist great internal pressure, by simply increasing the thickness of the metal. It is far more effective to employ a stronger material. A hollow cylinder made of ordinary gun-metal, for instance, the thickness of which is equal to the diameter of its bore, is capable of resisting safely a strain of only 488 atmospheres; while the same cylinder, if made of Krupp's gun-steel, is capable of resisting an internal pressure of 1,646 atmospheres. A gun-metal cylinder of the greatest thickness of metal could never resist such a pressure without its bore suffering deformation.

In the case of a hollow cylinder open at both ends, but subjected to an external pressure P_o, all the internal strains in radial and tangential direction are compressive strains, the tangential strains being the greatest. Let J_c denote the compressive working strain, then for the thickness of metal the value is

$$r_i \times \left[\sqrt{\frac{J_c}{J_c - 2P_o}} - 1 \right]$$

If $P_o = \frac{1}{2} J_c$, the thickness becomes infinitely great, consequently P_o has to be less than $\frac{1}{2} J_c$.

On comparing the above formulæ with those for internal pressure, it is seen that hollow cylinders, made of a material of which the working strain for compression equals that for tension, are able to resist an internal pressure much better than an external pressure of the same magnitude.

The Author next considers hollow cylinders open at both ends, and subjected to an external and internal pressure. It has been shown already that hollow cylinders made of gun-metal or cast iron are not able to resist a higher pressure than 540 to 740 atmospheres; but even stronger metals, such as steel-bronze or steel, require very great thickness to withstand internal pressures of 1,600 to 1,700 atmospheres. The cylinders in this case will have to be made from 1½ time to twice the diameter of their bore in thickness; and the construction of homogeneous hollow cylinders becomes altogether impossible for an internal pressure of 2,000 atmospheres, owing to the small part which the outer portions of the cylinder take in resisting the pressure.

The application of a proportionate external pressure alone will make hollow cylinders, of moderate thickness of metal, capable of resisting very high internal pressures without straining the material beyond the working strain.

When both external and internal pressures exist, they may be expressed by two equations, which show in a remarkable manner the influence of the external pressure in reducing the strain on the material. In this case, the external pressure must be calculated from whichever formula gives its lowest value, so as to avoid too great a strain in the radial direction, although the material is thereby not fully strained in the tangential direction. A small amount of overstraining, however, in the radial direction does no harm to a tough metal; the only consequence will be a slight increase in the bore, but at the same time the resistance of the material in the tangential direction is increased by augmenting its density at the inside. The manufacture of the steel-bronze guns is based on this principle.

W. R. B.

Corrosion of Steam Boilers supplied with Feed-water from Surface-condensers. By D. Stapfer.

(Bulletin de la Société scientifique industrielle de Marseille, 2nd quarter, 1876, p. 61.)

The corrosion observed in steam boilers supplied from surface-condensers, is attributed to the fat substances which are drawn into the condenser by the steam from the cylinders. These are found by analysis to consist of fatty matter and oxide of iron in nearly equal proportions. Slight traces of copper in these deposits, have induced the opinion that the fatty acids begin by attacking the copper of the stuffing-boxes and the pumps, and that iron, both cast and wrought, is only disengaged by a molecular interchange in contact with the salt of copper. The Author is of opinion that the phenomena of corrosion may be explained without any reference to copper, and he deduces from the results of experiments, that the grease is the active agent in the corrosion of boilers. In the localities of a boiler which are but moderately heated, the grease, made rancid during its passage into the cylinder, and led off by the condensed water, attacks the iron; or it forms a soap with the salts of lime, which disturbs the ebullition of the water in the boiler, and leaves muddy deposits upon the sides. When this grease or soap forms, with the sulphate of lime, an adhering crust on the parts exposed to the fire, it may thereby isolate the plate from the water; and so soon as the plate becomes over-heated at any point, sulphurets are generated, which corrode the furnaces, and especially the tubes, with great rapidity. Deposits of pure calcareous salts, on the contrary, break up and detach themselves when the plate becomes overheated, so that the water regains access to the surface, but the greasy deposit is much less brittle; it repels the water, and, when overheated, it still further repels the water by the gaseous matter disengaged by its decomposition. In this way, sulphurets may be formed, even under water.

An example in point is quoted, in which the corrosion of the tubes of a boiler took place on the lower side, in the form of a number of small holes a few millimètres in diameter. Here the insoluble oleate of copper could not have taken any part, for it must have been deposited on the upper side. The action must have been excited either by the easily melted oleate of lime, which could have run down to the under-side of the tube, or rather by the fat acid directly, which, when the boiler was emptied, was collected in drops, like those of oil, under the tube, and, assisted by the oxygen of the air, made holes of the size of the drops.

Carbonate of soda has, in marine boilers, been mixed with feed-water, in quantity sufficient to saponify the greasy matter, but it has not had the effect of prolonging the duration of the boilers. From this and other evidence, the Author concludes that, if the fatty acid is admitted into the boiler, the only course is to permit it to expend its energy upon a metal or upon an oxide for which its affinity is greater than it is for iron. For this object, the feed-water must be delivered below the furnace, near to the comparatively cool surface at the bottom, and injected upon blocks of zinc or heaps of the metallic oxide of lead or of zinc. Better still is the plan of arresting the grease by filtration or by decantation before it can enter the boiler. The grease is entirely transformed or acidified when it enters the condenser, and the Author gives a proof of acidification in the fact that, when he injected bicarbonate of soda into a condenser, it was promptly cleared of fatty deposit. After having described a few contrivances for purifying the water, he recommends a simple process of decantation, preceded by treatment with litharge, which forms and precipitates a heavy soap; or the process of passing the water previously, with lime, through a filter-press.

Finally, the Author proposes the use of mineral oils for lubrication, as they are not convertible into acids; although there is a difficulty arising from the formation of a stiff gum, analogous to caoutchouc, which adheres to the piston-rods.

D. K. C.

On a Particular Cause of Corrosion in Steam Boilers.

By V. Wartha.

(Der Berg Geist, No. 75, 1876.)

In a manufactory in Upper Hungary, recently opened, the feed-water heating tube of the boiler became seriously leaky a short time after the engine was set to work. On removing it, in order to replace it by a new one, the substance of the plate, which was of good fibrous iron, was found to be reduced from 0·276 inch to 0·157 inch, and in places to be completely corroded into holes. The main boiler was intact, and was covered with a thin scale of carbonate of lime. A fragment of the worn plate, examined by the Author, was found to be filled in the hollows with a brown fatty substance, which, on being subjected to analysis, appeared to consist mainly of ferric oxide, with a considerable quantity of fatty matter, besides some carbon, and the ordinary mineral components of boiler incrustation. When treated with ether, a dark brown substance dissolved out of the fatty matter, and by evaporation, gave a sticky brown substance, insoluble in water, that proved to be ferric oleate, the presence of oleic acid being determined by saponification with baryta. Glycerine was not found, showing that no neutral fat was present. A synthetical experiment proved, that when a mixture of oleic acid with water and iron filings is heated, hydrogen is evolved with great energy, and a brown substance is produced, which contains 11 per cent. of ferric oxide, is soluble in ether, and in every way resembles that found in the boiler.

The cause of the corrosion is, therefore, to be attributed to the adhesion of oleic or similar fatty acids in drops to the side of the heating tube; such acids, derived from the lubrication of the piston and cylinder, being introduced by the current of exhaust steam from the engine, used in heating the feed-water. The iron, at these points of adhesion, is attacked with the production of a salt, which, diffusing through the adherent mass, is decomposed when brought into contact with water under pressure at a high temperature; ferric oxide is produced, and the acid being liberated attacks a fresh portion of the exposed surface, cutting deeper into the plate, until it is completely perforated. The action is cumulative, so that a small quantity of the acid is sufficient to penetrate a plate 0·276 inch thick in a short time.

The action of oleic acid upon the main steam generator of a boiler has been investigated, among others, by Bolley in 1861, and Birnbaun in 1874; but the case described does not appear, according to the Author, to have been previously published.

H. B.

Non-condensing Woolf Engine and Boiler. By V. Cadiat.

(Bulletin de la Société scientifique industrielle de Marseille, 2nd quarter, 1876, p. 71.)

This engine and boiler were designed for working economically with steam of an absolute pressure of 11 atmospheres, this high pressure having been adopted as a compensation for the want of a cold-water supply for a condensing engine. The boiler consists of a cylindrical barrel, 24 inches in diameter and 17 feet 6 inches long, from which depend eight tubes (*bouilleurs verticaux*), 10 inches in diameter and 6 feet long, made of $\frac{9}{32}$-inch plate. The tubes, nearly vertical, are slightly inclined to right and left alternately, that the flame in its course may the better strike against them; and each tube contains an interior tube, about 5 inches in diameter, which descends nearly to the bottom of the outer tube, and is placed there for the purpose of circulating the water and steam. The steam is collected by a perforated pipe in the upper part of the cylinder. The fire-grate is 35 inches long and 30 inches wide, and is placed below one end of the cylinder. The flues, which envelop the whole of the boiler, except the upper portion of the cylinder, are constructed in three horizontal stages, which are traversed successively by the products of combustion mounting from one to another. The lower ends of the vertical tubes descend a few inches through the hearth or sole of the lowest flue, into a vault underneath, and they are closed by cast-iron doors. Thus the sediment that collects in the tubes may be extracted at convenient times, and any liability to blocking up the tubes by sediment and impeding the circulation is prevented. This boiler has been at work under an effective pressure of 150 lbs. per square inch, for eight months without interruption, and has given great satisfaction. The engine is horizontal, on the Woolf system. The second cylinder has a capacity five times that of the first cylinder. Steam is cut off in the first cylinder at from 50 to 86 per cent. of the stroke, making an ultimate nominal expansion of from 6 to 10 times. The steam is admitted to the first cylinder by a pair of valves controlled by a link-motion, having a slotted lever, by which the travel and thereby the point of expansion may be varied. Indicator diagrams, taken at a speed of 50 revolutions per minute, prove that the distribution is good: the intermediate fall of pressure between the first and second cylinders does not exceed 1½ lb. per square inch. The indicated back pressure in the second cylinder is 3 lbs. per square inch. The fuel (coal) consumed amounts to from 10 to 12 cwt. per day. The indicator power is said to be upwards of 23 I.HP., and, allowing ten hours a day of active work, it would appear that the fuel consumed was under 5⅓ lbs. per I.HP. per hour.

D. K. C.

Experiments on the Steam-Engine in 1873 *and* 1875.

By G. A. HIRN, DWELSHAUVERS-DÉRY, W. GROSSETESTE and O. HALLAUER.

(Bulletin spécial de la Société industrielle de Mulhouse, 1876, p. 187.)

These experiments were made according to the analytical and experimental method developed in the second volume of M. Hirn's recent work on Thermodynamics.[1] They show that the steam-engine cannot be considered as a simple mechanism, of which the functions may be analysed without reference to the physical properties of the organs, but that the surfaces of the cylinders act as thermic reservoirs, which absorb and give up heat alternately to the steam during its working and ejection. Errors, not of 2 or 3 per cent., as anticipated, but of 40 and 50 per cent., are thus caused between estimated and actual result. As an instance, steam superheated to 446° Fahr., in which condition it may almost be considered a permanent gas, falls, on entering the cylinder, to its point of saturation, and even condenses in part. This is discouraging, because it shows how difficult it is to form a general theory of the steam-engine, how an improvement in one direction is counteracted in another, while it explains the frequently vast difference between theory and practice. The experiments were made specially with the intention of discovering what amount of expansion of steam gives the maximum economy with a certain pressure and a certain amount of superheating; also the difference between a condensing and a high-pressure engine.

In order that a body after being expanded through heat may perform external work, it must be cooled, and thermodynamics teach the simple relation which exists between the maximum work obtained, the quantity of heat furnished, and the absolute temperatures between which the operations are performed—the range. The maximum temperature even for superheated steam must be below that at which lubricating materials are decomposed, or about 482° Fahr., while condensing water cannot be relied on below 68°, so that the maximum of possible effect is 249 French HP. per 100 calories expended, nearly 250 HP. per 400 British thermal units.

The machine employed was a beam engine, with a single vertical cylinder, furnished with four distributing valves, and supplied sometimes with saturated and sometimes with superheated steam.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 292.

In one instance it worked at high pressure without a condenser; the expansion could be varied at will. The observations made may be grouped in three separate series:—

I. The weight of steam consumed, and of hot water ejected from the condenser, obtained by two distinct gaugings, the difference being the injection water. The feed-pump drew the boiler supply from a cask alternately filled and emptied, and the ejection water from the condenser was received into a masonry tank and, flowing through an orifice in a thin partition, was deduced from the mean of the day's quantities above the orifice.[1] A table gives the date of observation, the extent to which the steam was superheated, the cut-off, and the weight of steam and that of the injected water per piston stroke.

II. The temperatures of the injection and ejection water were observed, and are given in a second table.

III. Estimate of the details of the work. Under this heading were considered not only the full pressure, expansion, and counter-pressure, and the real indicated effect, but also the pressures at different points in the cylinder, where it is wished to study the heat state of the steam. M. Regnault's tables give all the data, such as the temperature, density, total heat of evaporation, and the internal heat of the steam, whilst the pressure at each moment was obtained by M. Hirn's flexion Pandynamometer, which utilises the beam of an engine as a spring, and measures its deflection. A third table gives the indicated HP. and revolutions per minute thus obtained. In a fourth table are shown the mean boiler pressure, and the temperature of the steam generated, as indicated by an open-air manometer, together with the values which lead to the first verification; that of the consumption of the motor per piston stroke for the calories produced by the steam, diminished by those absorbed in work and external cooling, must be found in the condensation water. The results obtained are, with one exception, correct within 1 per cent.; the cause of the error of 3 per cent. in the excepted case cannot be traced.

Influence of the surface of the cylinder. Extent of the error which may be committed in neglecting their action. For this purpose it is necessary to calculate the weight of steam used at various points of the course of the piston. The volumes generated by the piston are obtained by direct measurement; the pressures, for instance, at the commencement of the expansion and at the end of the stroke give the corresponding values of the densities of dry steam, and it is quite easy to obtain the weight of vapour present at these two points. The difference between the weight of vapour directly gauged and that equivalent to the commencement of the expansion and end of the stroke, as given in a fifth table, is generally a loss, but sometimes a gain.

The loss was at first attributed to an escape between the piston and cylinder, but this would not explain the case when the calculated was in excess of the measured weight; the piston may then be considered hermetical, and the key to the loss is derived from the same proposition of physics from which Watt derived the theory of the condenser, viz., that when steam is introduced into a reservoir of invariable dimensions, whose walls are not all of the same temperature, the final tension is always that which corresponds to the lowest temperature.

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[1] This method of testing steam-engines by measurement of the condensed water is that employed by Messrs. B. W. Farey and B. Donkin, jun.—Sec. Inst. C.E.

When the steam is taken direct from the boiler, it is a saturated vapour of which a portion condenses on the slightest fall of temperature, and as the steam generally carries a portion of water with it, an addition of heat vaporises this water. The steam enters the cylinder, the surfaces of which are of a lower temperature than itself, and of considerable extent relative to its volume. The steam condenses, giving up to the metal its heat of evaporation; the piston moves slowly at first, and then more quickly, offering new and increased surfaces to condense the steam; the valve closes, the expansion begins; without interrupting the exchanges of heat between the originally heated and the cold part of the cylinder, the steam and its liquid evaporate on one part and condense on another, until at the end of the stroke the steam is in a condition different from that existing at the end of the admission. The same changes take place with superheated vapour, which loses not only the superheat, but a portion of its heat of evaporation, and condenses.

Hitherto this loss of heat has certainly not been denied, but its effect has been considered insignificant, for the reason that gases are bad heat-conductors, and the time of a piston stroke has been considered too short to allow of a considerable exchange of heat by radiation; this, however, takes place by direct contact and condensation, not by radiation, and produced a condensation in one case as high as 36 per cent. at the commencement of the expansion. In certain cases very slight quantities of water have been found: thus with superheated steam, and a cut-off of $\frac{1}{5}$, $\frac{1}{2}$, the condensation has been only 1, $2\frac{1}{2}$ per cent., whilst with saturated vapour, and a cut-off of $\frac{1}{7}$, there have been condensations of 25 to 36 per cent. M. Hirn explains this by assuming that in the interior of the mass, and notwithstanding the condensation which always takes place on the metal, the steam remains superheated at a temperature superior to the tension reached.

The next question is what becomes of the heat in the cylinder sides, and it is necessary to define the internal heat (U) of a mixture of steam and water: it is the total heat of the mixture, diminished by the portion which the external work has cost. To know what takes place in expansion, it is necessary to compare the internal initial and final heat, as well as the amount absorbed in the interval, by the work of expansion. This comparison is made in Table 6, in which in two cases the internal heat is greater at the end of the stroke than at the commencement of the expansion, and yet the work of expansion has caused a disappearance of heat, and the gain of heat must have been at the expense of the cylinder walls. But this is only one side of the question, for the cylinder walls contain more heat than they have given up, and the remainder has to be accounted for. It is the so-called R *c* cooling at the condenser, and is a loss caused as follows:—When the moment of release arrives, the valve opens to the condenser, the pressure rapidly falls to that corresponding to the temperature of the condenser, and is less than that of the end of the stroke; the temperature of the cylinder sides is greater than that corresponding to the pressure; evaporation and boiling occur, and a quantity of heat is sent to the condenser without producing any useful effect. To recapitulate, R *c* is the heat taken from the cylinder sides during the release, increased by that of the work of ejection; it should be found *in toto* in the condensation water. On the other hand, being in the cylinder sides, it does not figure in the expression for the final internal heat U; the difference between these quantities gives it. A Table contains this comparison, the greatest ratio of difference being about 1 per cent. The only case in which R *c* was a negative quantity was in the high-pressure trial, in which the steam was found dry at the end of the stroke. This is a thorough confirmation of the reason assigned for the loss in other cases; a loss amounting to as much as 22 per cent., and one that should, if possible, be reduced.

To show how the errors committed on the expenditure of steam may extend to the estimate of the work, it should be ascertained whether the steam condensed during the admission really corresponds, 1st, to the work produced by expansion; 2nd, to the external cooling of the cylinder; 3rd, to the internal cooling of the cylinder whilst the steam is injected into the condenser. M. Hirn has done this by considering the active portion of the sides of the cylinder to form, as it were, part of the steam and water present, and to have their temperature; and he has thus obtained an integral of all the quantities which enter into the question, viz., the mass of steam, the absolute temperature, the heat of evaporation, and the capacity, which is compared with the value taken directly from the curves, showing an accordance to within 1 per cent. Another table gives the proportion of vesicular water either attached to the sides, or in suspension in the steam and carried to the condenser.

The direct practical consequences of the experiments are next considered, and the following recapitulatory table is given. (See next page.)

In comparing the results of 1873 and 1875 under similar conditions, there are anomalies explained by the cylinder having been altered, the exhaust ports increased, and the lead made greater, which improvements have caused a diminution of 10 per cent. in steam consumption. The question of superheating is not further discussed, as it is shown to give an economy of 20 per cent.; but in conclusion the three following matters are considered:—

1. The influence of expansion. Admissions varying from $\frac{1}{7}$ to

Date of Trial.	State of Steam.	Pressure of Steam at end of Admission. Per sq. inch.	Work in HP.	Consumption of Steam per I. HP. per Hour.	Proportion of Water at end of Stroke.	Proportion of Heat carried off by R c.
					Per cent.	Per cent.
18 Nov., 1873	Steam superheated 447·8°F.(231°C.) Admission ¼	56·248 lbs.	144·36	16·902 lbs.	12·0	7·8
28 Nov., 1873	Saturated steam Admission ¼	53·724 lbs.	136·46	22·057 lbs.	25·2	15·6
26 Aug., 1875	Steam superheated 419° F. (215° C.) Admission ⅕	58·904 lbs.	135·77	15·404 lbs.	17·5	9·7
27 Aug., 1875	Steam superheated 433·4°F.(223°C.) Admission ½, valve partly closed	32·802 lbs.	125·17	18·037 lbs.	13·2	10·5
7 Sept., 1875	Steam superheated 383° F. (195 C.) Admission ⅐	55·651 lbs.	113·08	15·677 lbs.	21·38	12·43
8 Sept., 1875	Saturated steam Admission ⅐	54·529 lbs.	107·81	19·613 lbs.	35·19	21·76
29 Sept., 1875	Steam superheated 428° F. (220 C.) Admission ½, valve more closed	24·830 lbs.	99·53	18·099 lbs.	15·85	14·21
28 Oct., 1875	Steam superheated 428° F. (220 C.) Admission ¼, without condensation	48·831 lbs.	78·30	27·093 lbs.	0·00	0·00

¼ give about the same consumption; these obtain in practice. Below ⅐, water at the end of the stroke and R *c* increase, and hence a point would be arrived at when the engine would be less economical, which has not, however, been discovered by the Author. On the other hand, an admission of ½ has been clearly shown to give larger expenditure.

2. The influence of wire-drawing the steam. Two experiments show that this is without effect on the economy; the steam was superheated in each case equally (see 27 Aug. and 29 Sept. in the table), and there was a difference of ½ atmosphere of pressure, but the consumption of steam remained the same. The difference between the results of the 26 and 27 Aug. is due to difference of expansion and not to wire-drawing.

3. Economy realised by application of the condenser. This is shown to be at least 43 per cent.

In the commencement it was stated that 249 HP. per 100 calories is the theoretical maximum, with a limit of temperature of 482° Fahr. The highest result obtained in these experiments is 135·77 HP. per 172·79 calories, or 31·5 per cent.

E. B.

The Mechanical Preparation of Anthracite.

By RICHARD P. ROTHWELL.

(Transactions of the American Institute of Mining Engineers, vol. iii., p. 134.)

Most of the anthracite coals of Pennsylvania are mined from seams 8 to 30 feet in thickness; seams less than 4 feet thick being considered unworkable. The system of mining adopted is in almost all cases that known as 'chamber and pillar work'; the chambers being 18 to 30 feet in width, and the intermediate pillars 12 to 20 feet. Owing to the hardness of the coal, powder is universally used for breaking it down. The amount abandoned in the mines is, on the average, from one-third to one-half of the total quantity in the beds worked over.

Lump coal is used only for blast furnaces. For nearly all other purposes Pennsylvanian anthracite is taken, which, owing to its hardness and its difficult ignition, is unsaleable for domestic and general manufacturing purposes, unless previously broken to small lumps. The breaking and sorting of the coal, to the several marketable sizes, is effected in large wooden erections, termed 'coal breakers,' placed close to the pit mouth, and fitted with the necessary machinery.

The sizes of broken and screened coal commonly made at a breaker are as follows:—

Name of Size.	Size of Square Mesh over which it passes.
Steamboat coal	4 inches.
Broken, or grate coal, or No. 1	$2\frac{3}{4}$ to $2\frac{1}{2}$,,
Egg coal . . . . ,, No. 2	$2\frac{1}{4}$,, 2 ,,
Large stove coal . . ,, No. 3	$1\frac{7}{8}$,, $1\frac{1}{2}$ inch.
Small stove coal . . ,, No. 4	$1\frac{1}{8}$,, 1 ,,
Chestnut coal. . . ,, No. 5	$\frac{5}{8}$,, $\frac{1}{2}$,,
Pea coal . . . . ,, No. 6	$\frac{3}{8}$,, $\frac{1}{4}$,,

Buckwheat coal, a still smaller size, is rarely made, except where the coal is washed on the screens, and where the chestnut and pea coal made have the larger of the dimensions above given.

The coal is broken by passing it between pairs of revolving rolls; the proportion of the smaller sizes that is made, being regulated, according to the demands of the market, by varying the distance between the rolls. In the best practice the rolls are of cast iron, fitted with sharp steel teeth, which may be replaced when broken, or taken out and sharpened as they get blunted in use. The teeth are preferably made curved, or 'hawk-bill' in shape, so that they may strike the coal with the point instead of with the side, and thus split the lumps into a few large pieces rather than crush them. In a well-arranged breaker there are generally either two or three pairs of rolls. The first, or 'crusher' rolls, are 18 to 36 inches in diameter, and 30 to 40 inches long, and are set so as to break the coal to go through a screen of $3\frac{1}{2}$ to

4½-inch square mesh. The larger sizes, 'steamboat' and 'broken' coal, from these No. 1 rolls, are often run again through a second or 'main' pair of rolls, when it is desired to make a larger proportion of the smaller sizes. The main rolls vary from 20 to 48 inches in diameter by 30 to 40 inches long, and are set to break to a 2¼ to 3-inch square mesh. When it is required to reduce the No. 2, or egg coal, to stove size, a third pair of rolls, the 'monkey' rolls, is added, 15 to 24 inches in diameter by 24 to 30 inches long, and set to break to a 1⅜ to 2-inch mesh. The surface speed of the rolls is from 700 to 900 feet per minute; the coal is broken up with less waste at the slower rate. The larger the rolls, also, the less is the proportion of waste made in breaking. Where large rolls are used, the teeth should be set point to point, not point to space as is usually done.

The revolving screens in which the broken coal is separated from the fine waste, or 'dirt,' and sorted to marketable sizes, are from 12 to 30 feet in length by 4 to 7 feet in diameter, and run at a surface speed of 130 to 200 feet per minute. They are nearly always made with a screening surface formed of cast-iron segments; these are light castings, weighing 7½ to 8 lbs. per square foot. Woven wire is in use only for screens of very fine mesh, such as those for separating the 'dirt' from the coal. Where the coal is washed in the breaker, water is run upon it as it passes through the screens. The coal is conveyed from one part of the breaker to another by inclined shoots or 'telegraphs,' on which the shale is picked out from it by hand. Some attempts have recently been made to separate the shale mechanically, by washing machines, as is done in other coal districts; but these have not been as yet generally introduced; though for the smaller sizes (No. 3 and under), machine washing would seem to be much more suitable than picking by hand. No attempts have yet been made to separate the shale from the coal in sizes below No. 4.

The breaker is a high timber-framed structure, 65 to 90 feet in height, from the 'dump platform,' at the top, to the railway tracks under the pockets for the sorted marketable coal below. Its cost, for a production of 600 tons a day, would be from $45,000 to $55,000, including all machinery; or for a yield of 1,500 tons a day from $75,000 to $90,000. The engine is placed in a separate building, to avoid risk of fire.

A general plan and two sections of a breaker are given in a plate accompanying the Paper. The chief points to be attended to in its design are:—(1) The dirt, or fine coal, as it comes from the mine, should be separated at the earliest possible stage, instead of carrying it down through the crushing rolls and allowing it to mix with the freshly broken coal. (2) All coal should have the slate carefully picked out before it is allowed to go through the rolls. (3) No coal should be put through the rolls that does not require breaking, all the small being screened out from the lumps, before these are broken. (4) Abundance of room and light should be provided, wherever the coal is to be picked by hand;

and the shoots should have just sufficient inclination to allow the coal to run down them without handling.

The proportion of waste made in this system of mechanical preparation varies with the nature of the coal, and the form of the breaking rolls used. In breaking up clean lump coal, the loss, in the form of fine coal, too small to be saleable, varies from 15 to 30 per cent.; and taking the coal as it comes from the mine, when it is of good quality, and mixed with but little 'dirt,' the loss in preparing it for the market is frequently as high as 40 per cent.

The cost of preparation may be stated in round numbers as varying from 35 to 45 cents per ton. Of this, about 10 cents per ton are for depreciation of machinery and breaker buildings, and the greater part of the balance is paid to the 'breaker boys,' who are employed to pick out the shale or 'slate' from the coal.

W. H.

On the Working of Thick Seams of Lignite in Bohemia.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 341.)

The working of thick seams of lignite in the district of Eger, in Bohemia, has recently been the subject of inquiry by a commission appointed by the Austrian Government. The method found to be best adapted to the district is that by stages, the excavated ground being filled up with earth brought from the surface. At the Antony Colliery in Davidsthal, belonging to Mr. J. D. Starck, this method has been developed to a considerable extent in the working of a seam 78 feet thick, and is found to possess advantages over all others that have been tried, especially as a prevention of underground fires. Only one-half of the total thickness of the seam (37 feet 4 inches) has been drained by a shaft; and this upper portion is worked on two stages—the first or upper one being 22 feet high, and the second or lower one 15 feet 4 inches; a thickness of 3 feet 3½ inches of roof being left in each stage. In the first instance, the ground is laid out by a level from the pit, which serves as a main drawing road; and from it, at intervals of 29 feet 6 inches, boards 6 feet 7 inches wide are carried at right angles towards the boundary. The coal is then taken away in a rib 10 feet 6 inches wide, on either side of the board, commencing at the far end and working back towards the main level, safety ribs or pillars of 3 feet 3½ inches being left at intervals of 29 feet 6 inches between each of the working panels. In working the upper stage, the height was divided into two sections, the lower one, of 9 feet 10½ inches, was first taken away, and the packing material was brought in through a special level driven in the upper section, and thrown down to the excavations below, which were filled in 'pari passu' with the removal of the coal. In the upper section, the packing material is brought through the same roads as are used in drawing coal to the shaft, the ground having already been partly laid out in pillar work. The cost of packing material is estimated at 1*s.* 1*d.* per ton upon the coal got in working away the panels, that obtained in driving roads, amounting to 40 per cent. of the whole, not being included. Upon the whole mine, when laid out for working upon this system from the beginning, and with complete filling up of the waste spaces, the cost is about 8*d.* per ton; and with only partial filling, 3*d.* per ton. Against this must be placed the saving from the suppression of underground fires, which are of common occurrence when this coal is got in pillar work. The loss of coal in safety pillars and roofs is about 15 per cent.; the latter cause of waste being diminished proportionally as the height worked in one stage is increased.

H. B.

On the Mineral Wealth of the Province of Madrid. By M. Piquet.

(Mémoires de la Société des Ingénieurs civils, 1876, p. 122, 1 pl.)

The Author having been employed during eighteen years in mining operations in Spain, and having during that period visited and examined mines throughout the whole of the country, proposes successively to give his impressions of its mining wealth, province by province, commencing with that of Madrid, to which his present observations are confined.

This district may be roughly said to consist of three geological belts, which traverse it in nearly parallel lines from S.W. to N.E., each of a width varying from 10 to 25 miles. The most northerly is chiefly composed of granite, gneiss, and mica-slate, with some rocks, belonging to the Silurian group, at the north-eastern extremity. The central belt, which surrounds the capital, is almost entirely composed of diluvial deposits, and the third, or most southerly belt, belongs to the tertiary series, traversed by extensive alluvial deposits on the banks of the rivers Tagus, Jarama, Henares, and Tajuña.

I. Metalliferous lodes are only found in the north-westerly corner of the province. They are almost entirely confined to argentiferous galena, but copper has also been worked on a limited scale.

As examples of the quality of ore, four mines are cited.

1. At Gargantilla de Buitrago the lode has been traced on the surface for a distance of 2,750 yards, a gallery 220 yards in length has been driven in the lode, and it has been proved to the depth of 77 yards. This gallery produced 100 tons of ore containing 50 per cent. of lead and 40 ounces of silver per ton of ore, and open cuttings on the external surface of the lode have produced 1,000 tons of ore containing 30 per cent. of lead and 20 ounces of silver to the ton. A shaft sunk upon the lode cut it at a depth of 65 yards, and the ore contained from 80 to 140 ounces of silver

to the ton, a portion, even richer, contained 300 ounces of silver to the ton.

2. At Bustarviejo a mine, called the Indiana, contains from 30 to 40 per cent. of lead, and from 50 to 80 ounces of silver per ton.

3. At Cervera two lodes, each of them 6 inches thick, supply an ore containing from 20 to 34 per cent. of lead and from 80 to 150 ounces of silver to the ton.

4. Lastly, the mine of San Francisco near Horcajuelo has produced ores containing upwards of 320 ounces of silver per ton.

The Author gives a further list of ninety-two metalliferous mines in this province which have been discovered, but are not yet worked on a commercial scale.

II. The non-metallic substances in this province are divided into three classes, viz.:—A. Those of the granite, gneiss, mica-slate, and silurian rocks; B. Those of the cretaceous group; and C. Those of the tertiary and diluvial formations.

A. Sulphate of barium is found in great abundance between the Escurial and Guadarrama, and at Colmenar de Arroyo. It is used for mixing with paper for the purpose of adding to its weight. Granitic kaolin, or porcelain clay, occurs in large deposits in many places on the banks of the Manzanares river, and in the royal park of the Pardo. It is in a purer state in regular beds, as pegmatite and halloysite, near Cercedilla, Galapagar, and Valdemorillo. Amongst others, the Author enumerates the mine of La Barranca; that of Lecharon, which has produced about 200 tons of kaolin per annum during the last ten years; that at Valdemorillo, which produces from 250 to 300 tons of kaolin per annum; and that near Galapagar, which produced between 5,000 and 6,000 tons of kaolin between the years 1817 and 1850, but has since been neglected, although the deposit is one of considerable magnitude. Anthracite of an inferior quality mixed with clay, in a bed about 1 yard thick, is met with near Horeajo, on the road from Madrid to Burgos, but it has not been worked.

B. The cretaceous group. The stone used for the numerous bridges, aqueducts, and other buildings on the extensive Lozoya Canal which supplies Madrid with water, all proceeds from this group. Hydraulic lime is found near Valdemorillo. Fire-clay is met with near Atalaya del Vellon. Small veins of lignite near San Augustin, Cabanillas, Guadalix, Chozas, Cerceda, and Manzanares have not been considered worth working.

C. In the tertiary formation, salt brine is occasionally met with.

Sulphate of soda occurs in great abundance in the rocks bordering on the rivers Jarama, Tajuña, and Tagus. It is in beds alternating with clay, and with the same stratification, sometimes anhydrous, at others hydrated, and more generally mixed in equal proportions with sulphate of lime or gypsum. The principal deposits are those at San Martin de la Vega, Tituleia, and Ciempozuelos on the banks of the Jarama; those of Chinchon and Villaconejos on the Tajuña, and those of Colmenar de Oreja and Aranjuez on the Tagus. The beds are from 8 to 10 yards thick and several miles in length; they contain an average of from 30 to 40 per cent. of anhydrous sulphate of soda, and about the same of anhydrous sulphate of lime, the remainder being clay. These deposits would be of considerable value were it not for the scarcity of fuel and the excessive cost of coal. Although enormous sums of money have been expended, the industry, which at one time seemed to promise great results, has now almost collapsed.

Limestone of a superior quality for building purposes is quarried at Colmenar de Oreja, and is much used at Madrid. Gypsum, or plaster of Paris, is abundant, and is used as a substitute for lime. Alabaster occurs near Arganda del Rey, but only in small pieces. Meerschaum, of an inferior colour and quality, is found at Vallecas, and is used in the manufacture of porcelain. At Cabañas, in the province of Toledo, and also near Aranjuez, it is of a good colour and with a fine grain, sometimes in pieces of 1 foot in thickness. A superior clay, from which immense jars for holding oil, water, and wine are moulded, is obtained at Colmenar de Oreja. Numerous beds of peat occur at the foot of the Guadarrama range of mountains near Navalpino, Navacerrada, the Escurial, and elsewhere, but it is usually not more than 1 yard thick. When heated in a retort it gives about 26 per cent. of charcoal, and about 3,500 cubic feet of gas per ton. Twenty-eight concessions to work these peat beds have been granted, embracing an area of nearly 3,000,000 square yards.

Asphalt, or bituminous conglomerate, in beds of about half a yard deep, is found in the valley of the Lozoya. Springs of mineral water, generally sulphurous, occur at El Molar, Loëches, and in several other places. The search for coprolites in the lower beds of the cretaceous formation is recommended, the formation being similar to that in which they occur in some parts of France, and the belief is expressed that artesian wells might be successfully sunk in the neighbourhood of Aranjuez, and at other points in the valley of the Tagus.

O. C. D. R.

On an Explosion in a Sinking at Niederölsnitz. By H. Kuhn.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 349.)

At the No. II. pit belonging to the Concordia Coal Company at Niederölsnitz, in Saxony, which was in course of being sunk to the coal measures and had reached a depth of 553 yards, an explosion occurred on the 8th of February, 1875, whereby three out of four men employed in sinking were killed, and considerable damage was done to the timbering and sides of the pit. From the statement of the survivor, it appears that three holes, each $2\frac{3}{4}$ inches in diameter, had been bored at the bottom, two of which were loaded with dynamite, and the third with a mixture of dynamite and powder. After lighting the fuses the men retired to a ladder platform, 72 feet above the bottom, which was protected by a safety stage 36 feet lower down. Two of the shots were heard to explode, after which a slight hissing noise was noticed, and an explosion followed which destroyed and filled up all the lower part of the pit for about 28 feet; caused more or less displacement among the ladders and timbering up to 98 feet, and above this point large quantities of stones and sand were thrown up, some of which reached the surface. The man who was rescued had been struck in the head by a ladder loosened by the explosion, and was not much injured except by the fall. The remaining three were dead, but not in any way externally injured; the cause of death being the rupture of the capillary vessels of the lungs, through a sudden and violent increase of air-pressure. Upon clearing the débris at the bottom, an unconsumed dynamite cartridge, besides a powder-can two-thirds filled, and a length of fuze were found; but no trace of fire-damp to account for the explosion. It would have been remarkable had such gas been met with, as the pit was still in the Permian strata, about 196 feet of that formation having to be penetrated before reaching the coal measures, according to the section of the adjoining No. I. pit, which was only 111 feet distant. The lower part of the pit wall, below 549 yards from the surface, was completely destroyed to a depth of 5 feet, and in one place a hole, resembling a level, extended back 26 feet into the rock. Between the depth of 557 and 560 yards, in subsequently continuing the working, gas was encountered in the rock, which issued at a considerable pressure for some months. The composition of two samples analysed was as follows:—

	A.	B.
Carbonic acid . . .	5·79	0·15
Hydrogen.	1·40 to 1·67	..
Nitrogen	93·47	85·05—85·58
Marsh gas	traces	14·27—14·80

Sample A was taken when the gas was first discovered, and B some time later.

There is great difficulty in accounting for the origin of this gas, the numerous authorities consulted by the Author having decided that no similar case had been previously observed. Gases of analogous composition have been observed in Westphalia, especially near Bochum, which contain up to 30 per cent. of nitrogen, besides carbonic acid and hydrocarbons in small quantity, in addition to a little oxygen, which is to be assigned to the presence of air. According to Von Meyer, such gas may be regarded as partly due to the changes going on in the formation of coal, and partly to the transformation of air, which may be partially deprived of its oxygen by certain coals, according to Richter's observation. The most probable cause for the explosion, therefore, seems to be that hollows in the strata immediately above the coal measures were filled with gas given off by the coal, where it was stored up under great pressure, until, in the course of the sinking, the walls of a principal reservoir were sufficiently attenuated to give way explosively; and after the first burst, the gas continued to escape for several months through the ground loosened by the first blast. The anomalous character of the accident, which was due to purely mechanical causes, the gas being uninflammable and incapable of producing an explosive mixture with air, is comparable, in fact, to the bursting of a boiler or air-reservoir under excessive strain, and seems to justify the adoption of a solution of this kind, which was suggested by Dr. Winkler.

H. B.

On new Bessemer Works in Sweden. By E. WESTMAN.

(Jernkontorets Annaler, 1875, p. 345.[1])

In the year 1874 new Bessemer works were started at Bangbro and Borgvik. The former comprises two blast furnaces with calcining kilns and other necessary accessories, in addition to converter house, foundry, and machine shops. The ground is also laid out for two more furnaces and their blowing engines, and forges and rolling mills, to be driven by water power; a constant supply of water being available even after several years of short rainfall. The blast furnaces are of the pattern now generally adopted in Sweden, the leading dimensions being as follows:—Diameter of the hearth 4 feet, of the boshes 9 feet, of the throat 5½ feet; height from the hearth to the boshes 15 feet, of the cylindrical belly 10 feet, of the upper conical stack to the enlargement for the gas-trap cylinder 18 feet, to the top of the cylinder 12 feet, giving a total height of 55 feet. There are two tuyeres, one in each of the side arches of the hearth, the front arch being used as a tapping place for Bessemer iron, while the fourth or back arch contains the cinder fall, and the tap-hole for such metal as is run into ordinary pigs or slabs. The configuration of the ground is such, that the ore-calcining kilns are placed 39 feet above the blast furnaces, and the latter 17 feet above the Bessemer house. The capacity of the furnaces is fifty-three charges of 8 tons, and, in ordinary work, from forty-eight to fifty charges are passed through daily, so that the descent of the charge requires rather more than twenty-four hours. The pressure of blast is from 2·09 inches to 2·13 inches of mercury, and its temperature rarely exceeds 600° Fahr. The charge in the Bessemer converter is generally from 70 to 100 cwt.; but when making ingots for large shafts, &c., heavier ones, up to 162 cwt., have been blown. The ordinary speed of the blowing engine is from 70 to 75 revolutions per minute, which is increased to 80 with the larger charges. The driving power is furnished by a turbine of 700 effective HP.

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[1] This article was translated into German by P. Tunner, and appears in "Zeitschrift des berg- und hüttenmännischen Vereines für Steiermark und Kärnthen," 1876, p. 33.

At first, only seven tuyere bricks with seven air-passages in each, or forty-nine in all, were used in the converter bottom, with which arrangement the blowing of a charge required from ten to twelve, or occasionally even fifteen minutes, the boiling period proper being from five to six minutes. The steel obtained in this way generally ran rather cold, the tapping holes in the ladle were often stopped, and a considerable amount of ladle scale was made; the number of tuyere bricks was therefore increased to thirteen, giving ninety-one air-passages ½ inch in diameter, which has resulted in shortening the blow to six or seven minutes, the boil requiring only one-half to three-quarters of a minute; and the product is so hot that even soft iron ingots, which are perfectly sound and free from red-shortness, can be made regularly, although no spiegeleisen is added. This is, however, partly due to the fact that a considerable addition of ores, containing lime and manganese, is made to the blast-furnace charges; so that the pig metal contains, as a rule, 2 per cent., and often more, of manganese.

The yield of ingots is remarkably high, being from 88 to 90 per cent. on the weight of the pig metal charged, in steel; but somewhat less when soft iron is made. The new Bessemer works at Borgvik have been added to an existing blast-furnace establishment, where there is sufficient water power for driving blowing engines, as well as the machinery of a proposed forge and rolling mill. The Bessemer blowing engines have two horizontal cylinders, 3¾ feet in diameter and 3¼ feet length of stroke, each being driven by its own turbine, under a head of 20 feet of water, and making from 32 to 43 revolutions, the same speed being maintained by the engines. The collective power of these turbines, at 60 per cent. effective duty, is about 500 HP. The volume of blast delivered by these engines has been calculated for several charges, with the following results:—The blowing of a charge of 61 cwt. occupied ten minutes, during which time 54,265 cubic feet are displaced by the pistons. Deducting from this quantity the amount of blast let off during the boiling period, which amounts to about one-half of that passed through the cylinder—or for three minutes, 8,139 cubic feet—there remain 46,126 cubic feet to be divided over 61 cwt. of cast iron, or 756 cubic feet per cwt. The amount actually passed through the converter, according to the generally received opinion, is only 600 feet per cwt.; so that the effective duty of the engines appears to be 79·3 per cent. A similar calculation, applied to the engines at Iggesund, showed a duty of only 70·6 per cent., the difference being attributed to the more unfavourable and greater rate of speed, which is 108 revolutions per minute, as against 32 to 35 revolutions at Borgvik.

H. B.

Qualities of Steel. By WILLIAM METCALF.

(Transactions of the American Society of Civil Engineers, vol. v., p. 323.)

The writer considers the question, whether the variations of structure in the ingot of steel, by which the steel-maker professes to keep the tempers regular, depend upon the variations in the proportions of carbon and iron alone. The answer is in the affirmative, and is based on the results of chemical analysis of twenty specimens selected from the ingot piles as marked for commercial use, ranged in the order of tempers, by the fractures as judged by the eye. The ingots were in two series, consisting of eight specimens and twelve specimens. In the first and second series respectively, the proportions of iron and of carbon were:—

	FIRST SERIES.			SECOND SERIES.	
	Iron, per cent.	Carbon, per cent.		Iron, per cent.	Carbon, per cent.
No. 1	99·554	0·404	No. 1	99·614	0·302
„ 8	98·673	1·166	„ 12	98·834	1·079
Average differences. .	·976	·952		·753	·647
Maximum „ . .	·182	·195		·160	·188
Minimum „ . .	·056	·011		·004	·004

The percentages of carbon increase in each case, continuously from No. 1 to the highest number. Mr. Metcalf concludes that the differences of structure in the cast ingot, observed by steel-makers, are entirely due to minute variations in the quantity of carbon in the ingot, and to nothing else; that these differences are so minute that actual uniformity, for all practical purposes, is easily attainable; and that the practice of guessing at the proportion of carbon in steel, by bending or nicking a bar, is utterly untrustworthy, compared with the method here exemplified.

D. K. C.

On the Causes affecting the Combustibility of Blast-furnace Gases.

By E. BELANI.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 444.)

The necessity of employing a highly heated blast in the manufacture of dark-grey iron for the Bessemer process has led to considerable improvements in the construction of hot-air stoves, more especially in the direction of the application of the waste gas of the furnace as fuel; unfortunately, however, it is now tolerably generally observed, that the gas from furnaces producing this class of iron is very much inferior in heating power to that obtained from charcoal furnaces heavily burdened for white iron. The Author has investigated this subject in two different works belonging to the Inneberger Haupt-Gewerkschaft in Styria, namely, the blast furnaces at Hieflau, smelting spathic ores with charcoal, and those at Schwechat, near Vienna, making Bessemer pig iron from the same ores and fluxes with coke. In the first case the averages of a great number of analyses made with Orsat's absorption apparatus gave the following as the composition of the gas corresponding to different makes of iron:—

	Carbonic acid.	Carbonic oxide.	Nitrogen.
Hartfloss, or spiegeleisen	12	20	68
Weichfloss, or granular forge pig . .	11·5	23·5	65
Mittelzeug, or mottled iron	15–11	18–22	67

In all these instances, the gas burnt well in the stoves and boilers without any auxiliary grate fire; when collected in a gasometer it was transparent and of a light bluish-grey colour.

At the Schwechat furnaces the following averages were obtained:—

Quality of Make.	Carbonic acid.	Carbonic oxide.	Nitrogen.
No. 1. Dark-grey, large-grained pig. .	10	24	65
„ 2. Metal rich in silicon made without limestone flux	9·6	25	65·4
„ 3. Mixed large and fine-grained grey pig	6·1	26·5	67·4
„ 4. Grey forged pig, furnaces working badly	5·5	30·0	64·5

Nos. 1 and 2 were the most readily ignited, but required a large grate fire to assist them in burning properly. The others were only burnt with difficulty. In every case the gas was milky and opaque, even when freed from dust and water, when collected in a glass gasholder, in a condition fit for analysis.

A comparison of the composition of the two classes of furnace gas shows that from the coke furnaces to be much richer in combustible gases than that of the Hieflau charcoal furnaces; nevertheless, the former can only be made to burn with difficulty. It is evident, therefore, that their peculiar behaviour is not to be accounted for on chemical grounds. The opaque milky gas was produced from the coke furnace, when on grey iron with a large proportion of flux in the charge (which would only burn while a flame was kept in front of the delivery pipe). When the gas was drawn over a layer of oil into the gasometer and allowed to stand for an hour, it became perfectly transparent and colourless, an exceedingly light white dust being deposited on the surface of the fluid and on the sides of the gasometer. This purified gas in every way resembled that from the charcoal furnace, burning readily with a pure blue flame, while in the crude gas the flame had a red or violet border from suspended matters. It was evident, therefore, that the difference was entirely due to the exceedingly minute solid particles in suspension, which acted prejudicially, not only by diminishing the combustible portion of the gas, already sufficiently diluted with inert gases, but also by absorbing a portion of the heat developed in combustion, which would otherwise be available for raising the temperature of the gaseous products. In order to obtain a measure of the effect of dust in lowering the heating power of a gas flame, experiments were made in the following manner. Ordinary coal gas was passed through a bottle containing finely powdered blast-furnace slag of a highly basic composition, which was kept in suspension by agitation, so as to make the gas take up as much solid matter as possible. The dust-laden gas was then burnt in a Bunsen burner, and the time required to raise the temperature of a given weight of water from 12° to 100° was noted. The times were—

I.	With gas free from dust	80 seconds
II.	„ „ containing 6 milligrammes of dust per litre.	92 „
III.	„ „ „ 9 „ „ „ .	105 „

The heating effect of the gas, therefore, appeared to be diminished in experiment III. by fully 30 per cent. as compared with experiment I. The flame of the pure gas was blue, that of the gas containing dust was reddish, or similar to what was observed with the furnace gas.

The matters in suspension in the furnace gases are, according to the Author, of two kinds; one being sufficiently heavy to deposit in the gas conduits and fire-places, and therefore, if the former are made sufficiently long and roomy, not likely to exercise any prejudicial effect upon the combustion; the second kind is, however, so very finely divided, that it is practically impossible to separate it in sufficient quantity to make a satisfactory analysis, but a qualitative examination showed it to contain silica, lime, magnesia, alumina, ferrocyanide of potassium, ferric oxide, sulphur, alkalis, and traces of ammonia and carbonic acid. Ammonia and cyanogen are often present in the gases of the Schwechat furnaces to a notable extent, and the Author remarks that the former may at times lead to considerable variation in the composition of the gas; he having observed that when the furnace was in the best working condition, the volume of carbonic acid found by analysis in the gas was often extraordinarily small. At such times, ammonia was always found both at the throat of the furnace and in the gas mains, the gas was very smoky, and could only be burnt with difficulty. It would seem, therefore, that the bulk of the carbonic acid may occasionally be removed by ammonia, the carbonate of ammonia formed going to increase the finely divided matter suspended in the gas. The production of ammonia is ascribed to the action of nitrogen in the blast and steam, upon lime and coal at a temperature a little above redness, a combination of factors which is quite possible in a blast furnace. The flue dust collected in the main gas tube often contains so much ammonia as to be plainly apparent by the smell after four weeks' exposure to the air. The dust collected upon a platinum capsule suspended inside one of the heating stoves was of the following composition:—

	Per cent.
Silica	28·42
Lime	36·16
Magnesia	6·20
Alumina	29·00
Manganous oxide	0·10
	99·88

It was entirely free from alkaline salts and iron, and was analogous in composition to an excessively basic slag. The blowing out of one of the furnaces at Schwechat has afforded an opportunity of testing the Author's views as to the origin of the dust. The operation was effected by charging a large quantity (40 tons of limestone upon 5 tons of coke) into the furnace above the last charge of iron-making materials. The gases were examined at intervals of about two hours during the descent of the charges, until the limestone appeared at the tuyeres and the blast was laid off. Full details of the examination are given, the general result being, that when the pressure of the upward current increased, so as to carry out more solid matter in suspension, the burning power of the gas diminished even when nearly free from carbonic acid. The last slag run from the furnace, although perfectly melted, and setting to a solid mass of a greenish-grey colour and breaking with a conchoidal fracture while hot, disintegrated violently when, by exposure to the air, for about an hour after tapping, it had cooled down. The result of this remarkable behaviour is an exceedingly fine greyish-white powder smelling strongly of hydrocyanic acid. That the disintegration was not due to water vapour in the air, or was analogous to the slaking of lime, was proved by allowing a fragment of the hot slags to cool in a desiccator over strong sulphuric acid, when it disintegrated in the same manner as in the open air. The composition of the slag was as follows:—

	Per cent.
Silica	24·30
Lime	34·81
Magnesia	5·84
Alumina	23·07
Manganous oxide	2·77
Sulphur	9·19
Iron	traces
	99·98

The exact analogy in composition between the slag and the flue dust, apart from the sulphur in the former, which is due to the very impure coke used, leads the Author to consider that the solid matter in the gases is essentially a disintegrated slag of this class, which is converted into dust and carried over mechanically by the upward current of gas; and although unable to describe the exact circumstances of its formation, he suggests that it may be produced when large quantities of limestone are charged into the furnace at one time, when the conditions may conceivably be locally similar to those prevailing when it is used in blowing out a furnace.

On the Zinc Ore Deposit of Moresnet (Vieille Montagne).

By O. Bilharz.

(Revue universelle des Mines, vol. xl., pp. 235–239.)

The deposit of calamine of the Vieille Montagne, Altenberg, or Kelmisberg, as it is variously styled, occurs in the lowest portion of the carboniferous limestone, which is here generally changed into dolomite. Its form is that of a basin, or the bottom of a boat, rising on one side to the surface, and plunging on the other at an angle of 13°, the greatest breadth being about 650 yards. The ore, which at the surface was composed principally of carbonate of zinc of extreme purity and richness, being entirely free from lead and blende, is intimately associated with dolomite, and must be considered as a pseudomorphous change of the entire mass of a limestone or dolomite bed into carbonate of zinc, and not as a deposit of secondary origin, like many of those in the neighbourhood.

The principal development of the deposit was near the surface, where it may have attained a length of 490 yards, and a breadth of between 110 and 160 yards, the whole space occupied by the basin having been filled with metalliferous matter. The largest and richest portion is near the northern extremity; this is known as the North Deposit, and is separated by a tongue of barren dolomite from another ore-bearing portion known as the South Deposit. In a south-west direction, the ore-band plunges below the dolomite, and has been proved to a depth of 120 yards, between which level and that at 80 yards the workings are now restricted.

A considerable change takes place in the character of the ore in depth, the pure carbonates of the surface becoming mixed with hydrated silicates, until at a depth of 80 to 90 yards the latter predominate. The anhydrous silicate, or Willemite,[1] one of the distinguishing peculiarities of Vieille Montagne, was found irregularly interspersed in large blocks, often exceeding 100 cubic yards in volume, in the mixed masses of calamine. The first workings seem to date from the fourteenth and fifteenth centuries, when the rich ore of the north crop was used by the brassmakers of Stolberg, and probably of Liége, in the manufacture of calamine brass. The first zinc furnace was established at Liége in 1806 by the Abbé Dony, who held the concession for working calamine for a term of years; but the amount of ore removed was not large, only the most compact and richest portions being taken, the earthy and less valuable qualities being left. It was not until 1846, under the Vieille Montagne Company, that the development of the workings was commenced, which ten years later reached colossal proportions. The production in 1855 was probably the largest ever attained in a mine of this class, namely, 137,000 tons of rough ore, which yielded 50,900 tons of picked and dressed ore fit for smelting. The ore was got in open workings up to 1856, when the bottom of the basin was reached in the northern deposit at about 30 yards below the surface; since which time the workings have been entirely subterranean, both in the northern and southern deposits. The estimated produce of the northern deposit from the commencement of the workings is about 660,000 cubic yards, containing about 1,500,000 tons of ore. This quantity contained from 200,000 to 250,000 tons of compact ore; the remainder in the earthy portions was thrown aside on the waste heap by the old miners, and was left untouched until 1847, when the first dressing floor was established. Since that date, more than 1,000,000 tons of ore have been recovered from the waste, and a further quantity of 300,000 or 350,000 tons still remains; making a total of about 1,350,000 tons of ore as the yield of the northern deposit. To this must be added, the produce of the southern deposit since 1850, which up to the present time amounts to 200,000 tons of compact and 300,000 tons of earthy ore, besides 130,000 tons in the underground reserves. The total amount of ore-matter in the whole deposit, therefore, may be estimated at nearly 2,000,000 tons, or about 1,500,000 tons of ore of the highest quality and yield.

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[1] Willemite is also found in the New Jersey zinc ores in considerable quantity —H. B.

The dressing floors are arranged for continuous work, all intermediate handling of the ore being avoided. The operations are divided into three classes. The first includes cleansing from mud and coarse sizing in drums; the second, concentration of the larger-sized grains, by classifiers and continuous jigging machines; and the third, the finishing processes for fine-grained materials, sands and slimes. The capacity of the dressing machinery is sufficient for the treatment of 200 tons of rough ore, with three sets of cleaning drums, the yield being up to 80 tons of dressed ore in the shift of ten hours. The ores, smelted on the spot, without any foreign admixture, are for the most part very refractory, as they contain both silicates and carbonate of zinc, mixed with earthy matters, chiefly silicates of lime and alumina, that are fusible at the high temperature required for reduction; an unfavourable combination, leading to the production of slags in considerable quantity, and a corresponding destruction of retorts. The furnaces are of the ordinary Belgian form, and originally contained seventy retorts each, which number has been augmented to one hundred and thirty, in accordance with the practice of most of the works around Liége. There are four blocks of furnaces in use, consuming on an average about 24 tons of ores and 33 tons of fuel in twenty-four hours; about 20 per cent. of the latter being anthracitic and the remainder bituminous coal. The yield of zinc in that time is about 8[1] tons, which is of high quality, and is exclusively used for making zinc white, and the finer kinds of castings for ornamental purposes, the so-called *fonte d'art.*

H. B.

On the Occurrence of Selenium in Fine Silver. By H. de Bray.

(Berg- und hüttenmännische Zeitung, vol. xxxv., p. 329.)

It is a tolerably common occurrence to find, in France, silver bars of a high degree of fineness ($\frac{995}{1000}$ to $\frac{998}{1000}$) unfit for making alloys for medals, plate, or similar ornamental purposes; the standard of which in France is 950 fine. The alloy made with such metal gives spongy and brittle ingots that can only be wrought with great difficulty; the surfaces of the finished work are covered with grey spots, which, although partially removed by polishing, reappear if the article is gilded. When such silver is alloyed with copper, there is a considerable amount of ebullition with projection of melted particles, even when the operation is performed, as is usually done, under a covering of charcoal. To establish the presence of selenium in such silver a residue is obtained by dissolving about 1,500 grains of it in nitric acid at 34° Beaumé, precipitating the silver as chloride by hydrochloric acid, and evaporating the clear solution to dryness, when selenic acid is found. This, when treated with a few drops of hydrochloric acid, gives selenious acid, which may be reduced to the elementary condition by sulphurous acid, when selenium is obtained as a black powder that can be readily collected and weighed. If the solution is effected with nitric acid, diluted to 10° or 15° Beaumé, grey crystalline lamellæ of a metallic lustre are obtained, which are selenide of silver, a compound which is not readily soluble in weak acids.

The Author has determined the presence of selenium in this way in nearly every specimen of silver from bars that had been separated from gold by acid, but he was unable to find it in such as was refined from lead by cupellation. By the addition of 6 grammes of selenium to 6½ kilogrammes of the latter kind of silver when melted, all the bad qualities observed in the metal from separated bars were produced. It is evident, therefore, that a considerably less proportion of selenium than 1 in 1,000 is sufficient to seriously injure the quality of silver for manufacturing purposes; as in the compound made for experiment, a considerable proportion of the selenium added was volatilised.

When seleniferous silver is alloyed with copper, the cause of the boiling observed is due to the oxidising effect of the suboxide of copper invariably contained in the latter metal, upon the selenium. This produces selenic acid which escapes, and the action, being independent of the air, goes on equally well under a protecting cover of charcoal. The grey spots on the wrought surfaces are produced by the dispersal of scales of selenide of silver through the mass of the metal. The source of the selenium is evidently to be looked for in the impurities of the sulphuric acid used in separating, which is now generally made from pyrites, and is commonly seleniferous. Besides the acid to dissolve the metal, a large excess of it is required to keep the silver sulphate in solution when separating the precipitated gold; and the whole of the selenium that may be present is sure to be precipitated with the silver when the latter is thrown down by metallic copper. It is therefore of considerable importance that pure acid should be used in parting, or else that the resulting silver should be subjected to an oxidising fusion in the air, either alone or with an addition of nitrate of soda, in order that the selenium compound may be destroyed.

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[1] The original gives "2,400 tonnes de minerai, 3,300 tonnes de combustible et 850 tonnes de métal."—H. B.

H. B.

Notes on the Treatment of Mercury in North California.

By Professor T. Egleston, New York School of Mines.

(Transactions of the American Institute of Mining Engineers, vol. iii., p. 273.)

Most of the quicksilver mines in California are situated in Sonoma and Napa counties. They yield some metallic mercury and ores of cinnabar; the former being found only in the altered rock near the surface, and passing into cinnabar as the workings are carried deeper. The ore is found in serpentine, and is often associated with chalcedony; it occurs in masses more or less irregular, but frequently yielding 3 to 10 per cent. of the metal, or more. Where the rock at the out-crop is not decomposed, it is often so filled with metallic mercury that, on striking a pick into it, a pound or more will sometimes spurt out; and in other cases, the surface earth resulting from its decomposition contains as much as 2 to 3 per cent. of mercury, and is worked as a valuable ore. The ore coming from the mine is carefully hand-picked; but no regular system of washing or concentration has been successfully introduced, though some rude attempts to enrich the fine ore in this way have been made.

The method adopted for obtaining metallic mercury from the cinnabar is to heat the ore to redness, in a current of air or flame, so as to oxidise the sulphur to sulphurous acid, leaving the mercury, which passes off as vapour and is collected in suitable condensers. The surface ore containing metallic mercury is not treated by itself, by simple distillation, but is worked together with that containing cinnabar.

The furnaces employed are very varied in construction and in mode of working. Among those described are retort furnaces of several forms, a modification of the old Idria furnace, and the continuous furnaces of Knox and Luckhart.

At Missouri mine, near Pine Flat, retort furnaces are used. The ore contains from ½ to 2 per cent. of mercury. The large pieces are crushed to about 1 cubic inch in size. The retorts are of two sizes, holding respectively 250 lbs. and 350 lbs. each, and they are charged every twelve hours. The exhausted ore, when drawn from the retorts, is at a cherry-red heat; and as it still contains some mercury, a considerable quantity of mercurial vapour is given off from it, so that the workmen are compelled to protect themselves by covering their mouths and noses with wet sponges tied on by bandages. A short connecting pipe passes from the back of each retort to a horizontal main, 6 inches in diameter, leading to the condenser. This consists of two cast-iron boxes, 3 feet by 2 feet, by 2 feet high, which are turned down in shallow cast-iron tanks containing water. From the bottom of these tanks, the mercury runs off continuously through a siphon pipe. A small fan-blower maintains a current of air through the retorts, sufficient to oxidise the sulphur of the cinnabar and to draw the vapours through the condenser. In addition to the pure mercury, a considerable quantity of fume, or "soot," as it is termed, collects in the pipes and condenser. This is cleaned out once a week, and worked with a hoe, with the addition of a little quicklime, to separate the mercury.

At the American mine, also near Pine Flat, the ore is crushed fine by stamps, and then mixed with 10 per cent. of lime, and treated in retorts. The average yield is 2 per cent. The retorts are of cast iron, and D-shaped, 9 feet long by 2 feet wide, and 18 inches high. Each retort treats three charges, of about 160 lbs., every twelve hours. The condensing arrangements are similar to those last mentioned. Most of the men employed were more or less salivated.

The modified Idria furnaces described in the Paper are those of the Redington Quicksilver Co. and of the New Almaden Co. At Knoxville, in August 1874, the Redington Co. had two Idria furnaces and two Knox furnaces in work, besides two of the latter in construction, and two more to be built. The Idria furnaces have, however, been abandoned at Knoxville, since the early part of 1875; and the masonry has been altered to Livermore's inclined continuous furnace, which is adapted to treat fine ores. The mine produces 700 tons to 800 tons of ore a week, containing on the average about 3 per cent. of mercury. The large pieces are broken by hand; and while the Idria furnaces were employed, the fine ore, including all small enough to go through a screen of ¾-inch mesh, was mixed with clay and made into lumps, or "adobes," which were dried and stored for use in them. The usual size of the adobes was 9 inches by 4 inches by 4 inches, weighing 12 lbs. each when dry. Seven men, at $2 each, made six thousand a day. Each of the Idria furnaces at Knoxville was capable of working one charge a week, of 100 tons of ore and four thousand to five thousand adobes. The furnace consisted of a fire chamber

20 inches wide, 17 feet long from door to door, and 20 feet high, which was separated by a wall of perforated brickwork from the ore chamber, 13 feet by 10 feet, and also 20 feet high and open at the top. A similar perforated wall separated the ore chamber from the nearer of two condensing chambers placed one behind the other, in which, however, but little mercury collected. Two such furnaces were connected by short flues to a main condenser, which consisted of a series of twelve chambers, 4 feet wide, 20 feet long from side to side of the block of masonry, and 20 feet high inside, built in one block, and firmly braced by wooden beams and $\frac{3}{8}$-inch round iron tie-rods. The whole was at first built of cut sandstone; but the work has been repaired with brick, which has been found more durable. The condensers communicated with a chimney flue, running up the hill-side, and ending in a chimney 50 feet high. The furnace was charged from the top; flues, formed of adobes, being built at intervals through the mass, to connect the perforations in the fireplace wall with those in the wall next to the condensers. The top of the charge was covered with clay and straw, on which were set large shallow cast-iron pans, kept filled with water. The exhausted ore was drawn from the furnace through openings in the sides of the ore chamber, at the bottom. With moderately rich ore, the yield amounted to two hundred flasks (containing 76½ lbs. each), or 15,300 lbs. of mercury a week. From five to twenty flasks of this were collected from the fume or "soot" that accumulated in the condensers and flues. The total cost of working, including wood for fuel, making adobes, and working up the soot, averaged, in 1874, $1·25 per ton of ore treated. No case of salivation of the workmen, except from carelessness, has been experienced here for many years.

At New Almaden there are six furnaces of the Idria type; one of 100 tons capacity, one of 70 tons, and four of 50 tons. The furnaces are built of brick, and each is connected with a series of brick condensing chambers; in addition to which four or five wooden condensers, filled with ordinary glass windows, for each furnace, have recently been added. The introduction of glass is said to give good results. The wooden condensers are chambers 26 feet long by 14 feet wide and 20 feet high. The top of the charge of ore, in the furnace, is covered with a layer of straw, 2 inches or 3 inches thick, then with ordinary clay and mud, and over this ashes. The soot is worked up by stirring it in boiling water, together with half its bulk of wood ashes. The mercury collects in the bottom of the vessel, and is run out through a siphon pipe.

The Idria furnace is now generally giving way, in California, to one or other form of continuous furnace. These are all shaft furnaces, in which the ore is charged at the top, heated by a fire at the side, as it passes down, so as to decompose the cinnabar and distil off the mercury, and it is drawn out at the bottom nearly exhausted of mercury, and so far cooled that no vapour escapes from it. The draught is maintained by a fan or blower, placed beyond the condensers, so that no fumes escape, even if an aperture in the furnace or condensers should remain open, and consequently, where this system of furnace is in use, cases of salivation are very rare.

The Luckhart furnace, one of this class, is in all respects similar to the Swedish furnace for roasting iron ores. At the Sonoma mine, where it is in use, nine-tenths of the ore treated consist of the surface soil from near the outcrop of the deposit, which contains from ¼ to ½ per cent. of mercury, and is made up into "adobes" measuring 5 inches by 4½ inches by 4 inches. The furnace is capable of treating 15 tons to 18 tons of ore a day, at a total cost of $1 per ton. The condensing apparatus consists of three sheet-iron cylinders, 5 feet apart; these are 14 feet high by 6 feet in diameter, and are cooled externally by water. There is so little sulphur in the ore that the sheet-iron condensers stand well, and the condensation is so perfect, owing to the comparatively small produce of the furnace, that a $20 gold piece, exposed for six weeks, at the top of the wooden chimney, remained entirely unaffected by mercury.

The Knox furnace, as in use by the Redington Co. at Knoxville, is 39 feet high, with a fireplace at one side, 17 feet 6 inches from the bottom. At the top it is 2 feet square inside, and widens out gradually to 7 feet square at the level of the fireplace; from this it narrows again to a section of 7 feet by 2 feet at the bottom. The flame from the fireplace enters the shaft by a series of openings, and is drawn by the exhausting fan through the mass of ore, heating it to moderate redness; and then, through a corresponding series of openings in the other side of the shaft, to a chamber communicating with the condensers. The air to supply the fire is heated beforehand, by admitting it through flues formed in the furnace walls. The furnace is estimated to hold 75 tons of ore, and works 24 tons to 25 tons a day; 1 ton being drawn from the bottom every hour, and a corresponding charge filled in from a hopper-bottomed charging-wagon at the top. Six of these furnaces, treating together from 900 tons to 1,000 tons of ore a week, are now in use at Knoxville. The fuel used, in the summer, is green, freshly cut brushwood, and in the winter ordinary good firewood. Two loads of brush, weighing about 1 ton, or 2½ cords of wood, are required to work the furnace every twenty-four hours. The draft is maintained by a Root's blower, placed beyond the condensers. To each furnace there are sixteen condensers, of cast iron, 8 feet long, 2 feet 6 inches wide, from 5 feet to 6 feet high, and cooled externally by water. The condensers are cleaned once a week, from deposited soot or fume; this is done by taking off the man-hole door, and cleaning down the sides with a hoe. The draft maintained by the blower is so strong that, if only one condenser is opened at a time, no vapours can escape. The ore treated yields, on the average, from 1 to 3 per cent. of mercury. The cost of working, in 1874, when two furnaces were in operation, averaged half a dollar per ton of ore treated.

Passing to the subject of condensers, the Author points out that their design and arrangement are even more important, as affecting the practical success of the process, than is the exact form of the furnace itself, and discusses the relative advantages of condensers of cast iron, stone, brick, and wood.

There would seem to be a decided advantage in the use of a dry fuel, such as coke or charcoal, instead of wood, in the treatment of the ores of mercury, as the absence of smoke and moisture from the products of combustion would diminish the quantity of "soot" deposited in the condensers and flues, and would thus allow of a larger proportion of clean liquid mercury being collected; and the amount of acid liquor condensed, and corroding the condensers, would also be less.

W. H.

Petrozcene and its Products. By Dr. H. W. C. Tweddle.

(Journal of the Franklin Institute, vol. lxxi., p. 204.)

Petrozcene is a hydrocarbon, and a product of the dry distillation of the residuum, or tar, from petroleum, newly discovered by Dr. Tweddle. It is sublimed near the end of the process of distillation, accompanying a thick resinous oil, with a specific gravity of about 0·980. The mixture, which has hitherto been valueless, is bright orange in colour, and rapidly becomes dark green on the surface, by oxidation. The petrozcene is separated by lixiviation with benzine, and is obtained as a yellowish-green, crystalline, extremely light precipitate. Its specific gravity is 1·2066, and it melts at from 420° to 425° Fahr. As a solid, it is not very hard, but brittle; it is inflammable, and burns with an extremely sooty red flame, emitting a slightly pungent empyreumatic odour. When it is distilled, it can be resolved into a series of interesting and beautiful products, ten in number, of which particulars are given in the Paper.

Petrozcene can only be produced in limited quantities. Fifty thousand barrels, equal to 2,100,000 gallons of Pennsylvania petroleum, of 48° Beaumé, yield only 400 lbs. of the precipitate. The resinous oil, which is accompanied by petrozcene, produces a valuable paint oil and varnish, which oxidises rapidly and dries hard. There is a marked analogy between petrozcene, and its products, and sulphur, with respect to physical characteristics.

D. K. C.

The Frue Concentrator. By Walter McDermott.

(Transactions of the American Institute of Mining Engineers, vol. iii., p. 357.)

This is an improvement on the well-known endless travelling belt used for dressing the slimes, or finest portions of the crushed ore, in many mining districts. In the ordinary machine, the inclined belt, or apron, moves slowly up against a thin stream of water and ore, delivering the concentrated ore over the upper end, and depositing it in a water-tank below, through which the belt travels in a reversed position, while the lighter refuse runs off with the stream of water from the lower end of the belt, through a waste launder. The arrangement and mode of working of the improved form of concentrator are precisely similar, except that a rapid lateral shaking motion is applied to the belt, in addition to its ordinary progressive movement. The sand is thus kept uniformly spread over the belt, and is prevented from "packing," or settling irregularly, and the water cannot cut channels through it. The travelling speed of the belt is from 100 to 120 inches per minute, and its simultaneous shaking motion is at the rate of two hundred vibrations per minute, with a stroke of 1 inch. A machine with a belt 20 inches wide, and 12 feet long on its upper or dressing surface (the size first made), is capable of dressing 3 tons of slimes in twenty-four hours. Many larger machines, with belts 4 feet wide, have since been built. The paper is illustrated by a plan and two sections of the machine described.

W. H.

On the Use of Cast-steel Drawing Ropes in the Pribram Mines.

By E. Langer.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 49.)

Up to 1872, the drawing ropes in the principal shafts at Pribram were made of iron wire, and consisted of thirty-six wires of No. 12 Styrian gauge, in six strands of six wires each, with a central wire and hemp core; the diameter of the finished rope being 0·79 inch, and the weight 42 oz. per yard. The tensile strength of the wire, which was of best Styrian charcoal iron, averaged 36·8 tons per square inch. At that period, the principal workings had already attained a considerable depth; the 27th level of the Adalberti mine being 906 yards, and the 26th level of the Maria mine 856 yards, below the shaft collar at the surface, respectively, in December 1871. Under these conditions the weight of the rope is considerable; thus, in the former case,

	Cwt.
The weight of the rope was	21·08
" " cage	9·80
" " tram wagon	5·88
" " net load lifted	15·37
	52·13

which gives a safety factor of only 2·7 times the working strain at the commencement of the lift; increased to somewhat more than 3 times, if the central wires are considered as bearing, which seems most likely to be the case. The use of stronger, and therefore heavier, ropes having a larger safety margin, would have required more powerful winding engines, and consequent stoppage of the work for some time. About this period the use of cast-steel wire, which for equal sections has about double the strength of wrought iron, first began to make way, and a change was decided upon. The material selected was the cast-steel wire made by Felten and Guilleaume, of Cologne, which has an average tensile strength of 74·3 tons per square inch. The section and weight of the rope are similar to those given above, and the maximum load of 52·13 cwt., as compared with the breaking strain, gives a safety factor of from 5·5 to 6·4. The first steel rope was brought into use at the end of January 1872; and up to the end of 1874, four had been worn out, the average life being twenty-two months, or about four times that of an iron wire rope.

The comparative result obtained by the two classes of ropes is then set out in detail in a tabular form, of which only the abstract is here given.

Averages.	Iron Wire.	Steel Wire.
Net load drawn . .	10,848 tons	47,210 tons.
No. of loads drawn .	13,668	59,115.
Height of lift . .	543 yards	543 yards.
Load	15 cwt. 2 qrs. 12 lbs.	15 cwt. 2 qrs. 23 lbs.
Net duty of rope .	5,387 million mètre-kilogrammes	26,519 million mètre-kilogrammes.
Cost of rope . . .	£44	£96 10*s*.
Life of rope . . .	5·5 months	22·3 months.
Cost per ton raised 1,094 yards . .	0·196*d*.	0·085*d*.

From this it appears that a steel rope may be counted upon to do five times the work of an iron one, and at one-half the price of the latter. The Author considers that the comparison would be more unfavourable for ropes of equal strength; but this could not be carried out at Pribram, as, owing to the great depth of the mines, iron wire ropes of equivalent strength to those of steel now in use would be heavy and unmanageable.

It is of great importance, with steel ropes, to have properly proportioned drums and guide pulleys, which should be about 25 per cent. larger than those used for wrought iron, on account of the greater rigidity of the material. The wire used should not be too hard, a tensile strength of 76·2 tons per square inch being the limit adopted; above this point, increased strength is accompanied with brittleness.

H. B.

Hemp Rope Gearing. By K. Keller.

(Zeitschrift des Vereines Deutscher Ingenieure, vol. xx., p. 397.)

The largest establishment where hemp rope gearing has been hitherto employed in Germany is the spinning mill at Hochneukirch, which, after having been partially destroyed by fire, is being refitted with similar appliances.

In all cases a broad wheel or drum is fixed on the crank shaft, serving at the same time as a fly-wheel, the diameter of which is about 100 times the diameter of the ropes to be employed. The diameter of the wheel on the first motion shaft is about one-half of the above. Both wheels have a number of conical grooves turned in the rim to receive the ropes, the object of the conical shape being to increase the friction between wheel and rope, and to diminish the strain on the ropes. The safe strain on a rope of hemp or jute, as now used, is 106·6 lbs. per square inch for the area of the circumscribed circle, or about 142·2 lbs. per square inch net. The sizes in use are 1·18 inch, 1·575 inch, 1·775 inch, 1·968 inch diameter over all.

The strains corresponding to the above diameters will be 118·8 lbs., 215·6 lbs., 272·8 lbs., 334·4 lbs. If the strain in the driving part of the rope is assumed to be double that in the driven part, the forces transmitted at the circumferences of the wheels will be 59·4 lbs., 107·8 lbs., 136·4 lbs., 167·2 lbs., and the work done, with a velocity of 32·8 feet per second at the rim of the wheel, will be equal to 1,953, 3,544, 4,484·5, and 5,497·2 foot-lbs., or 3·6, 6·5, 8·6, and 10·1 HP.

The number of ropes required is ascertained by dividing the total HP. to be conveyed by the HP. which one rope of the size fixed on will convey, as given above. To this number one more is to be added to avoid the overstraining of the other ropes in case one of them breaks.

In adjusting the gear, the slack rope should always be placed on the top, so that it takes up the least room, and the pulleys should not be arranged vertically one above the other. In consequence of the smooth working of this gear, the wear and tear in the bearings, &c., is greatly reduced, and the repairs are few, as may be seen from the fact that a set of ropes remains in perfect working order for two years at least, and the working expenses in a case of rope gearing, where 400 HP. were transmitted, amounted to about £20, or 1*s.* per HP. Another advantage of this gear is, that the number of ropes can be diminished when less power is to be transmitted, by which the friction on the journals is reduced.

A table is annexed to the original, giving the leading dimensions of rope gearing as applied to seven factories in various countries.

W. R. B.

Steam-aided Reversing Gear for Winding (and other) Engines.

By A. Stévart.

(Revue universelle des Mines, vol. xl., p. 101.)

With large winding engines, if they are fitted with slide-valves, there is a difficulty in reversing them by mere manual power. This difficulty has been overcome by the auxiliary steam-cylinder of M. J. Goffint. The inventor claims for his arrangement that the engine-driver has to deal with only the usual hand-lever, and that he deals with it in the ordinary manner. The hand-lever is loose on the reversing shaft, and is prolonged so that its lower end may lie between two tappets forged on a "plate," which "plate" is keyed on the reversing shaft, and is the means by which that shaft is worked. There are springs which tend to keep the tail of the hand-lever midway between the two tappets. On an upward prolongation of the "plate" a small beam is pivoted, the top end of which is attached to a pin in the hand-lever, while the lower end, which is nominally in the line of the axis of the reversing shaft, works the slide-rod of the auxiliary steam-cylinder. On moving the reversing lever, its tail-piece passes through the clearance space, before it presses one of the tappets, on the "plate." This makes a relative movement between the lever and the "plate," which movement, though small, is sufficient to work the little beam, and thus to operate on the slide-valve of the auxiliary cylinder, admitting steam on to its piston. The rod of this piston is attached to the "plate," and thus the very preliminary movement, in either direction, of the hand-lever is the means of giving the appropriate steam pressure to the piston of the auxiliary cylinder. Care is taken to keep the auxiliary cylinder so small that its piston cannot do the work without the aid of the pressure of the man's hand, who is thus still left in full control. Many engines have been so fitted with great success.

A. B.

Theory of Centrifugal Fans. By M. Arson.

(Bulletin de la Société des Ingénieurs civils, 1876, p. 728.)

This Paper, with the discussion upon it, turned chiefly upon the question of the best form of the blades of ventilating fans. It appeared, from results of experiments made by M. Glépin on the ventilation of mines by means of centrifugal fans, that, while the maximum efficiency with flat blades adjustable to various inclinations amounted to 20 per cent., it amounted to 28 per cent. with curved blades. On this point M. Badois questioned the value of a theory by the application of which an efficiency of only 28 per cent. was obtained. For blowing fans from which a certain absolute velocity of blast was required, he maintained that the form of the blades must be of another curvature. The angle of intersection of the ends of the blades with the circumference should be greater in proportion as the final velocity of discharge from the blades was increased, until it would become an obtuse angle; and the outer portions of the blades would become concave to the current, whilst the entering portions were convex.

M. Lencauchez maintained that the extent and the direction of the curvature of the blades had absolutely no influence on the efficiency of the fan; and in support of this opinion, he quoted the results of experiments he had made on the pressure of air at different points in the same radius of a fan constructed with flat blades. The pressure was equal to that of the atmosphere for a considerable portion of the length of the blade, measured from the inner edge; and it was only on arriving within a very limited zone near the outer end that the pressure was raised. He inferred, from these observations, that it was only the outer ends of the blades which performed useful work, and this afforded, he suggested, an explanation why the efficiency was but slightly modified by the curvature or the inclination of the blades. M. de Dion, though he was of opinion that the efficiency was but slightly influenced by the curvature, and that it depended chiefly upon the speed of rotation, nevertheless maintained that the curvature was very useful as a guide for the air drawn into the fan.

D. K. C.

On a Differential Anemometer. By M. Arson.

(Mémoires de la Société des Ingénieurs civils, 1876, p. 505.)

When a current of air flows through a tube which is restricted or reduced to a smaller diameter at some portion of its length, the velocity of the current is accelerated in passing into the restricted portion, and is retarded in passing out of it into the tube of normal diameter; and if the restriction be so formed as to accelerate and retard the current without shock, there is no loss of head in the operation. M. Arson employs this principle in his anemometer; but he modifies the form of the restriction, in so far that, whilst the approach to the restriction is gradually contracted, the exit from it is square, so that the current passes abruptly from the orifice into the tube of full bore. The pressure, or rather the degree of "vacuum," at the exit is measured by a water-gauge attached at the entering angle or corner, and the difference of the heights $(h_o - h)$ due respectively to the external or barometrical pressure and the internal pressure is equal to the difference of the heights $\left(\frac{V^2}{2g} - \frac{V_o^2}{2g}\right)$ due to the normal and maximum velocities; that is,

$$h_o - h = \frac{V^2}{2g} - \frac{V_o^2}{2g}.$$

M. Arson so adjusts, by preference, the sectional area of the restriction that $\frac{V^2}{2g} = 2\frac{V_o^2}{2g}$; whence the difference $(h_o - h)$ becomes equal to $\frac{V_o^2}{2g}$. The difference $(h_o - h)$ is measured directly by the water-gauge, and thus, by simple computation, the normal velocity, that is, the velocity of the wind blowing through the tube fairly directed towards it, may be determined.

That the quantity $\frac{V^2}{2g}$ may be equal to $2\frac{V_o^2}{2g}$, the sectional areas of the tube and the restriction must be as 1 to $\sqrt{2}$, or 1 to 1·414. The formula employed by M. Arson is the usual formula for the velocity due to the head, measured by the height of a column of air equal in weight to the pressure signified by the water-gauge. Very full tables are appended to the Paper, containing the velocities due to water-pressures varying from 1 to 100 millimètres, or from 0·039 inch to 4 inches; for barometrical pressures of from 72 to 78 centimètres, or from 28·4 to 30·7 inches of mercury; and for temperatures ranging from − 4° to + 104° Fahr. From direct observation, it appears that the results obtained by the formula are to be reduced by the co-efficient 0·94, to give the actual velocities.

D. K. C.

Apparatus for Determining the Resistance offered to Ships by Experiments on their Models.

By A. Lettieri.

(Rivista marittima, vol. ix., p. 110.)

This is an apparatus for experimenting on the resistance offered to the models of ships. The inventor considers that the determination of the resistance encountered by a vessel moving at different velocities in still water is a most important question, which has been solved by Mr. Froude. The law which this gentleman has formulated, by which to deduce the resistances met by a vessel from those encountered by its model, Signor Lettieri considers to have been fully verified by the experiments made by Mr. Froude on the "Greyhound" and its model.

The further prosecution of similar experiments Signor Lettieri thinks useful, or even necessary, with the view of ascertaining, before the launch of a vessel, the curve of the resistance that it will encounter with different loads and displacements. Being unacquainted with the apparatus used by Mr. Froude, Signor Lettieri has invented one of his own, the description of which he illustrates with a drawing.

In experiments of this nature the elements to be determined are two: the uniform velocity, and the resistance encountered at that velocity. The first of these is obtained by the measurement of the space passed through in a unit of time. It is therefore desirable to have an apparatus which shall graphically denote this velocity by a curve, and refer it to a measure of the resistance.

To effect this, Signor Lettieri has designed a vertical cylinder (the drawing shows the length to be fourteen times the diameter, but neither scale nor dimensions are given), which revolves on a fixed axis. The upper part of this axis sustains a pulley, and a second pulley is fixed beneath the cylinder, with a small drum on its axis. A line attached to the drum passes over the upper pulley, and sustains a scale pan, to which is fixed a pencil, the point of which presses against the cylinder. The model is attached by a line to the lower pulley, so that the descent of the weight corresponds to the movement of the model through the water; while the weight itself is a measure of the resistance. Movement is given to the vertical cylinder by means of a pair of conically toothed wheels, one of which is attached to the cylinder itself. The motion of the latter being thus made uniform, and its velocity known, the curve traced on it by the pencil will indicate the relation between the movement of the model and that of the cylinder, and will form a regular spiral when both movements are uniform. The remainder of the Paper is occupied by an algebraical investigation of the curves thus to be obtained, and by the relation between the weight placed in the scale pan, and the resistance encountered by the model in its passage through the water.

F. R. C.

On Electric Transmission by the Earth. By TH. DU MONCEL.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1366; vol. lxxxiii., pp. 17, 182, 307, and 501.)

Among the experiments undertaken in America in 1842 and 1844 by Morse, Gale, Vaïl,[1] and Rogers on electric transmission without conducting wires, of which the most important were made on the Susquehanna river, at Havre-de-Grâce, near Baltimore, some have a certain scientific interest if the deduction made by these experimentalists is to be regarded as general, namely, that the maximum electric effect transmitted from one bank of a river to another obtains when the lateral distance of the two submerged plates is triple the width of the river. It appears to the Author that this deduction cannot be established in a general manner. If a river were insulated from the earth, and presented only a conductivity analogous to that of a prism of conducting matter, it would be easy to understand that the current passing by the plates in connection with the receiver would be augmented in energy proportionally as the derivation between the two other plates was increased in length. It could also be understood that, if at the same time there were an increase of the resistance of the metallic circuit, which connected the system of plates on each bank of the river, there would be produced a maximum of which the conditions would be based on the relation existing between the distance of the plates and the width of the river. But a river is not insulated from the earth, and experiment shows that beyond a certain limited distance the conductivity of the liquid is compounded with that of the earth, so that the resistance presented to electric transmission maintains a constant value. Now this constant value represents precisely the maximum distance of the plates on the banks, and this maximum, consequently, cannot be a function of the width of the river, at least for a moderately great width. The Author believes that, if in this kind of transmission the resistance of the earth be interposed between the two communication-plates at each station, as Gintl and Bourbouze have done, these plates would be placed in conditions of sufficient removal from each other to give to the derived current all the power that it can furnish. For the rest, the value of the resistance of the earth is variable, and depends on the state of humidity of the earth around the communication-plates, on their dimension, on the direction of the current transmitted, and on the currents which may arise at the contact of the plates with the earth-strata. Taking the water-conduits in the Grenelle quarter, and an iron plate of 6·45 square feet, buried at a depth of 3 feet and 5,680 feet from the point of communication with the water-pipes, it was found that the resistance of the earth was represented by 8,890 feet of the telegraph wire when the plate was positive, and by 11,850 feet when the plate was negative. Similar experiments are detailed. In ordinary telegraphic transmission these differences of earth resistance pass unnoticed; but in transmission based on the derivation of currents they need grave consideration. In a series of experiments conducted by the Author on the Seine, the chief difficulties were an action resulting from the difference of humidity of the earth around the plates serving as electrodes, and an action which could only be the result of a great difference of surface between the two electrodes. In some laboratory experiments intended to confirm these results, with two plates, one buried in dry and the other in wet sand, the earth-current was always directed in the exterior circuit from the plate immersed in the dry sand, or least moist sand, to that in the wet or moister sand, that is, with oxidisable metals; but with inoxidisable metals, such as platinum, the effect was often diametrically opposed. With plates in water the current was always directed in the exterior circuit from the large to the small plate, and this with all metals. With the great and variable effects due to difference of surface of the electrodes, there are thus three sources of difficulty in electric transmission by the earth alone. Apart from this principle of transmission, the Author deduces from his experiments that advantage in an earth return circuit obtains only when the resistance of the metallic circuit exceeds that of 6¼ or 9½ miles of telegraph wire.

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[1] See Vaïl "On the American Electro-magnetic Telegraph," published in 1847, p. 60 of the English edition, and p. 66 of the French edition.

Polarisation currents produced in contrary direction to the local current disappear much less quickly when a small plate is positive than when it is negative. Effects of polarisation are more energetic with small than with large plates, the polarisation being chiefly determined by the positive electrode. Consequently, the smaller the positive electrode in an electrolyte the more energetic the polarisation, and the longer is it maintained. The Author has assured himself that, when a moist conductor of small resistance is arranged in such manner as to constitute an electric generator, the electro-motive force from which may be feeble, this may furnish in a metallic circuit of considerable resistance a sensible and constant current, the intensity of which may be much superior to that of the current furnished by a battery of a considerably greater electro-motive force flowing through the same metallic resistance and humid conductor. This is due in great measure to polarisation effects developing themselves in one case on the two electrodes, and in another case on only one electrode, that which disengages hydrogen. Where the generator is constituted by a humid conductor, the electrode at which oxygen is disengaged is the electrode attacked, and that, consequently, where the electro-motive force is developed; but when a battery-current flows through the humid conductor, this electrode is polarised by the oxygen, and an electro-motive force is created in opposite direction to the current transmitted. From these considerations it is to be perceived that the telluric current developed at the place of contact with the earth of the earth-plates of a telegraph line may not be much affected by the resistance of a telegraphic circuit, but the current from a battery may be very much affected. The importance of this reaction depends on the tension of the battery, on the resistance of the humid conductor, and on several other circumstances. To determine the importance of the actions brought into play at the contact of earth-plates with the earth, the Author has studied the influence of the nature of the metal of which the plates are constructed. The following table gives the electro-motive forces of two moistened metal plates separated by a sample of silex from Hérouville:—

	E. M. F. in Daniell's Cell.		E. M. F. in Daniell's Cell.
Zinc-platinum . . .	0·28	Platinum-brass . .	0·0033
Zinc-brass	0·26	Brass-tin	0·0084
Zinc-lead	0·135	Brass-lead	0·0048
Zinc-copper . . .	0·06	Brass-iron	0·0044
Zinc-tin	0·06	Copper-tin	0·011
Zinc-iron	0·016	Copper-iron . . .	0·0071
Platinum-iron . . .	0·034	Copper-lead . . .	0·0044
Platinum-tin . . .	0·033	Iron-lead	0·0044
Platinum-lead . . .	0·022	Tin-lead	0·0033
Platinum-copper . .	0·0044		

Knowing the value of these currents, the Author measures the polarisation currents produced by the action of the battery, thus, with zinc-platinum plates:—

	Intensity of Current.		Polarisation Current.
	Initial.	After 5 mins.	
1. With circuit only, including galvanometer, equal to 460 miles of telegraph wire with one Daniell element.	+ 34°	+ 18°	– (80° – 16°)
	+ 30°	+ 16°	– (85° – 14°)
2. With the same circuit and an additional resistance of 1,260 miles	+ 26°	+ 16°	– (73° – 11°)
	+ 21°	+ 13°	– (76° – 10°)

As a result of the experiments, it is found that the current from a Daniell cell, the electro-motive force of which is nearly five times greater than that of the couple constituted with the Stone, in traversing a circuit of 1,500 miles resistance, gives only half the deflection of the current with the Stone, and quicker diminution. The current diminishes with the battery, and increases with the Stone used as generator. It is to the double effects of polarisation produced by the passage of the current through a humid conductor that the enfeeblement of the current is due; and because the local current produced under the influence of a humid conductor does not pass through a medium so susceptible of furnishing polarisation effects, it maintains its power longer. The current from a single cell is, therefore, more easily affected than is the current from several cells, although these may produce a greater polarisation effect. The Author then proceeds to consider the effects produced by varying oxidation of the earth-plates, to account for some anomalous measures obtained with plates of the same metal, giving experimental data obtained by an artificial earth connection. According to the researches of M. Becquerel, with inoxidisable plates, a simple difference in the action of the water on the substances entering into the composition of the earth at the two extremities of the telegraphic line suffices to produce these currents, because this difference of action has the effect of putting the earth at each place, and consequently the plates, into different electrical states. Immersing two plates of zinc, one into each of two wells situated 530 feet from each other, the Author found considerable currents result when a galvanometer was introduced into a wire circuit of 9,450 feet resistance connecting the two plates. Water drawn from the two wells, and arranged to form a galvanic couple with two plates of zinc and a porous cell, gave a similar electrical action. This action was discovered to be due to minute traces of sulphuretted hydrogen contained in one of the waters, the impurity, however, being apparent to only searching analysis.

To deduce from the values representing the resistance of a circuit completed by the earth the resistance of the earth itself, the Author has employed a modification of Ohm's law, in which is stated the electro-motive force, e, of the telluric current combined with that of the polarisation current. Designating by E the electro-motive force of the battery employed, by R its resistance, by l the known resistance of the metallic portion of the circuit, by ρ the unknown resistance of the earth, by t the total resistance of the circuit completed by the earth, by r, r' the resistances in the rheostat in trials with two directions of current, the intensity of the current in the two circuits of a differential galvanometer may be represented by two expressions of different form, which, at the moment when the deflection becomes nil, should have the same value, and, for voltaic and telluric currents in opposite directions, lead to the equation,

$$\frac{\mathrm{E}\,t}{\mathrm{R}\,(t+r)+t\,r}=\frac{(\mathrm{E}-e)\,r}{\mathrm{R}\,(t+r)+t\,r}, \text{ or } \mathrm{E}\,t=(\mathrm{E}-e)\,r.$$

For the case of currents in the same direction, this equation becomes,

$$\frac{E\,t}{R\,(t+r')+t\,r'}=\frac{(E+e)\,r'}{R\,(t+r')+t\,r'},\ \text{or}\ E\,t=(E+e)\,r'.$$

From these equations,

$$t=\frac{2\,r\,r'}{r+r'},\ \text{and}\ \rho=\frac{2\,r\,r'}{r+r}-l,$$

expressions which become, in distinguishing the electro-motive force, e', of the current of polarisation,

$$t=\frac{E-e'}{E}\,\frac{2\,r\,r'}{r+r'},\ \text{and}\ \rho=\frac{E-e'}{E}\,\frac{2\,r\,r'}{r+r'}-l.$$

The value t being thus determined, it is easy to deduce the electro-motive force, e, of the telluric current, which is,

$$e=\frac{E\,(t-r')}{r'},\ \text{or}\ e=\frac{E\,(r-t)}{r},\ \text{or}\ e=\frac{(E-e')\,(r-r')}{r+r'}.$$

From his experiments, and these considerations, the Author finds that, with regard to telegraphic transmission by the earth alone, or rather by the water of a river, as attempted on the Seine during the Franco-German war, the resistance of the water would be blended with that of the earth at probably a less distance than 1,084 feet. It may be concluded that, under the best conditions, the resistance of the earth varies from that of 2½ to 3 miles of telegraph wire,[1] and is far from nil, as generally supposed, becoming very great if wells or reservoirs of water do not interpose in the communication, and, finally, enormous if large electrodes, such as gas and water mains, are not at command.

P. H.

A New Peroxide of Manganese Battery. By G. Leclanché.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 54.)

The Author admits that the use of peroxide of manganese in batteries is not new, but at the time when it was first employed no satisfactory results had been obtained. This was due, on the one hand, to imperfect comprehension of the part played by the material, and of its use in conjunction with sulphuric acid or chloride of sodium; or, on the other hand, by employing it in the state of fine powder, a condition which paralyses the action of the battery and prevents the profit of the proper conductivity of the substance. All oxides of manganese are not equally serviceable in the construction of batteries; that known as needle-manganese gives the best results. This substance, instead of being reduced to powder, should simply be broken into coarse grains. When mixed with a nearly equal volume of retort-carbon, broken in the same manner, the resistance of the element is not only diminished, but the electro-negative condition of the plate forming the positive pole is increased, and polarisation effects are decreased by the larger surface given to this electrode. In the battery invented by the Author in 1866, the depolarisation is effected by disoxygenisation of the peroxide. When the depolarising substance is simply piled around the positive pole by hand, under a maximum pressure of some few lbs. per square inch, it possesses only a relatively small conductivity, and its consistence is so slight as to render the use of porous pots necessary. Submitting the substance to considerable pressure, it is rendered a much better conductor, and acquires a consistence sufficient to permit dispensing with the porous vessel. The mixture giving the best results under compression consists of 40 per cent. of peroxide of manganese, 55 per cent. of retort-carbon, and 5 per cent. of gum-lac. These substances, after being ultimately mixed, are subjected in a special shell mould to a pressure of 300 atmospheres and to a temperature of 212° Fahr. The addition of 3 to 4 per cent. of bisulphate of potash in the interior of the agglomerate mass greatly diminishes the resistance, and helps to dissolve any oxychlorides deposited in the pores. The electro-motive force of the new element is 1·5 Daniell's, and a single element will heat to redness a small platinum wire sufficient to ignite gas.

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[1] Presumably 4-millimètre wire.—P. H.

P. H.

On the Derivation of a New Fundamental Law in Electro-dynamics. By PROF. R. CLAUSIUS, Hon. M. Inst. C.E.

(Journal für die reine und angewandte Mathematik, vol. lxxxii., p. 85.)

This was the subject of former communications of December 6th, 1875, and February 7th, 1876.[1] The Author now proceeds to give a very detailed proof of his fundamental law, without entering into special considerations as to the nature of electro-dynamic action. Weber reduces electro-dynamic phenomena to one law, which determines the force exerted between two particles of electricity. If e, e' represent the particles of electricity, supposed to be concentrated at points whose distance is r, the following equation is given by him for the repulsive or attractive force, as the case may be:—

$$F = \frac{e\,e'}{r^2}\left[1 - \frac{1}{c^2}\left(\frac{dr}{dt}\right)^2 + \frac{2}{c^2}r\frac{d^2 r}{dt^2}\right],$$

where c is a constant.

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[1] *Vide* Pogg. Ann., vol. clvi., p. 657, and vol. clvii., p. 489.

Weber's theory is, that equal quantities of positive and negative electricity, flowing in opposite directions with equal velocity at the same time in a conductor, constitute an electric current. This conception introduces complication. The simpler theory of there being only one kind of electricity in a current has been expressed lately in a new form by C. Neumann, similar to one published by Riemann in 1854, viz., that the negative electricity is bound up in some way with the molecules of the conductor, and that the positive is alone free to form the current in that conductor.

These theories are then examined mathematically by the experimental law, that a constant current in a closed and fixed circuit exerts no force on static electricity, and the examination proves that the fundamental expression given by Weber cannot agree with the theory of only one kind of electricity flowing in a current, because, in integrating out the expression for the force over the whole circuit, the values are not zero, as they should be according to experimental facts.

The Author next proceeds to establish from first principles the expression for the force components in the direction of the co-ordinate axes, first for a special system of co-ordinates, and he then reduces this to any system of co-ordinates. His method of procedure is to form an equation containing all possible terms that can occur up to differential co-efficients of the second order, and then by examining these expressions, by known experimental laws, to reduce the equations to their simplest forms by freeing them of all superfluous quantities, or those which vanish through the above treatment.

He first obtains X, the x-component of the force, in the following form:—

$$X = \frac{x - x'}{r^3} + X_1 + X_2 + X_3,$$

the plain letters referring to one point and the dashed to the other at which the particles of electricity are supposed concentrated.

He then derives X_2 from the experimental law, that a constant current flowing in a closed and fixed circuit exerts no force on statical electricity, X_1 from the converse of the above law, viz., that a quantity of statical electricity exerts no force on a constant current flowing in a closed and fixed circuit, and X_3 from the Amperian expression of the force, which a closed current exerts on another closed current, and from the experimental law that a constant current in a closed and fixed circuit does not alter the intensity of another constant current flowing in a closed and fixed conductor. Moreover, he makes use of the following law of induction, viz., that, if a conductor s is fixed in the neighbourhood of a conductor s', but in the latter the strength of the current increases from zero up to a definite value, or if the strength of the current in s' is kept constant at that definite value, but s is brought from an infinite distance to the defined position, the inductive action in s will in both cases be equal.

He thus obtains the following equation :—

$$X = \frac{x - x'}{r^3} + \frac{d\,[J\,(x - x')]}{d\,s'}\,\frac{d\,s'}{d\,t} + \frac{d^2\,[G\,(x - x')]}{d\,s'^2}\left(\frac{d\,s'}{d\,t}\right)^2$$
$$+ \frac{d\,[G\,(x - x')]}{d\,s'}\,\frac{d^2\,s'}{d\,t^2} + \frac{d}{d\,t}\left(H\,\frac{d\,x}{d\,t}\right) - k\,\frac{d}{d\,t}\left(\frac{1}{r}\,\frac{d\,x'}{d\,t}\right)$$
$$+ \left\{\frac{k\,(x - x')}{2\,r^3}\,\frac{d^2\,(r^2)}{ds\;ds'} + \frac{d\,F}{d\,s'}\,\frac{d\,x}{d\,s} + \frac{d^2\,[E\,(x - x')]}{ds\;ds'}\right\}\frac{d\,s}{d\,t}\,\frac{d\,s'}{d\,t}.$$

By the application of the law of conservation of energy, he simplifies the expression, and produces the following equation for the component of the force in the direction of the axis of x, and similar expressions for those of the other axes :—

$$X = -\,\frac{d\,\frac{1}{r}}{d\,x}\left(1 + \frac{k}{2}\,\frac{d^2\,(r^2)}{d\,s\,d\,s'}\cdot\frac{d\,s}{d\,t}\,\frac{d\,s'}{d\,t}\right) - k\,\frac{d}{d\,t}\left(\frac{1}{r}\,\frac{d\,x'}{d\,t}\right)$$
$$+ \frac{d}{d\,x}\left[\frac{d^2\,R}{d\,s'^2}\left(\frac{d\,s'}{d\,t}\right)^2 + \frac{d\,R}{d\,s'}\,\frac{d^2\,s'}{d\,t^2}\right],$$

where R is an unknown function.

The expression for electro-dynamic potential is according to Weber—

$$V = -\,\frac{1}{c^2}\,\frac{e\,e'}{r^2}\left(\frac{d\,r}{d\,t}\right)^2;$$

according to Riemann—

$$V = -\,\frac{1}{c^2}\,\frac{e\,e'}{r^2}\left[\left(\frac{d\,x}{d\,t} - \frac{d\,x'}{d\,t}\right)^2 + \left(\frac{d\,y}{d\,t} - \frac{d\,y'}{d\,t}\right)^2 + \left(\frac{d\,z}{d\,t} - \frac{d\,z'}{d\,t}\right)^2\right];$$

according to the Author, if the function R is made equal to zero, which is the most probable value—

$$V = -\,k\,\frac{e\,e'}{2\,r}\,\frac{d^2\,(r^2)}{d\,s\,d\,s'}\,\frac{d\,s}{d\,t}\,\frac{d\,s'}{d\,t};$$

This equation may be put in the form,

$$V = k\,\frac{e\,e'}{r}\,v\,v'\cos\epsilon,$$

where $v\,v'$ is the velocity of the particles of electricity, and ϵ the angle between their directions.

The force component in the above terms becomes, by putting $R = 0$,

$$X = -\,\frac{d\,\frac{1}{r}}{d\,x}\,(1 - k\,v\,v'\cos\epsilon) - k\,\frac{d}{d\,t}\left(\frac{1}{r}\,\frac{dx'}{d\,t}\right).$$

By applying the above general expression of X to the determination of the force, which an element ds of a galvanic current suffers from an element ds' of another galvanic current, the following expression is obtained for the force component in the direction of the axis of x, and similarly for the other axes:—

$$k\,i\,i'\,ds\,ds'\left(\frac{d\frac{1}{r}}{dx}\cos\epsilon - \frac{d\frac{1}{r}}{ds}\frac{dx'}{ds'}\right),$$

in which the unknown function R does not occur. This expression can alone satisfy the theory of only one current flowing in a circuit, and at the same time agree with the law of the conservation of energy, as to the mutual action between two particles of electricity.

P. H.

On the Distribution of Magnetism at the Surface of Magnets.

By MM. TRÈVE and DURASSIER.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 814.)

In the principal results obtained by the Authors in their researches on the magnetisation of steel, they have insisted on the establishment of a direct and analytical method which should not necessitate a rupture of the metal, as under this condition the structure of the material may be greatly modified, and the results observed may not necessarily be in relation with the molecular condition. The Authors give a series of curves representing the magnetic distribution at the surface of three steels differently carburetted and tempered, one in water and the two others in oil. The Authors consider that it may be premature to seek to establish a formula capable of representing a phenomenon in which so many diverse functions intervene. A general law is given, which is that the more a steel is carburetted, the greater is the magnetism condensed towards its extremities. Conversely, the less the steel is carburetted, the further the magnetism extends and appears on its surface. The law is simple with the results obtained with extreme steels of which the purity is beyond doubt, but it is not so clearly manifest for intermediate steels with even minute quantities of foreign elements, such as silicium, phosphorus, manganese, &c. This variation leads to the hope that a magnetic analysis of steels may indicate to the metallurgist what weight of silicium, phosphorus, and manganese may be capable of giving to steel the same physical properties as a determined weight of carbon. To attain this end, so far as concerns manganese for example, there would be taken a manganated steel bar identical in form and weight with that of a series carburetted only, but containing, besides a certain proportion of carbon, a known portion of manganese. The magnetic analysis completed, it should be determined, by trial with a series carburetted only, which of these would give analogous results to that furnished by the manganated sample. It is evident that the excess of carbon of the sample containing merely carbon would be precisely equivalent in effect to the manganese of the manganated sample. Such a system would throw a great light upon the influence of the different foreign elements on the physical properties of steel. For the carrying out of this work there would be necessary a series of steels containing only carbon and iron.

P. H.

A New Electric Lamp. By P. Jabloschkoff.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 813.)

This is a note communicated to the Academy by M. Denayrouze, in whose workshops the Author has perfected the subject. The invention dispenses with all the mechanism usually employed in ordinary electric lamps. The new luminous source is formed by two carbon spindles fixed parallel at a small distance from each other, and separated by an insulating substance which disappears equally with the carbon. When the current commences to pass, the voltaic arc plays between the two free extremities of the two spindles. The nearest layers of insulating matter are volatilised in such a manner that the carbon and the insulating matter disappear progressively as combustion proceeds, a process which may be compared to the combustion of the wick and the wax of a candle respectively. This idea, which appears to be only a simplification, may lead to important results. The heat of combustion of the carbon, which with the ordinary regulators is lost in the air, is utilised in the fusion and volatilisation of the insulating material. The composition of the insulating material may be largely varied, but the Author employs, for the most part, earthy materials. Substances ordinarily the most infusible, it is well known, are easily volatilised when introduced into the voltaic arc. Therefore such insulating substances as sand, powdered glass, or cements may be used; the most simple mixture appears to be composed of powdered glass and sand.

The light, which is added to that of the electric light by the incandescence of the insulating substance, produces effects analogous to that of the Drummond light. Thus with a given electro-motive force a greater light can be obtained than with an ordinary regulator. With a single electro-magnetic machine of the ordinary kind, three sources of light can be maintained.

P. H.

The Electric Light: its Lighting Power for Force expended.

By PAUL HEILMANN-DUCOMMUN.

(Bulletin spécial de la Société industrielle de Mulhouse, 1876, p. 175.)

This Paper, which forms one of a number read at the celebration of the fiftieth anniversary of the Société industrielle de Mulhouse, is descriptive of experiments made with four Gramme machines employed to light the works of M. P. H. Ducommun. These experiments also include a series of photometric measurements made by Professor Schneider, which are described in the same volume. It was sought to determine, by combined photometric and dynamometric observations, the motive power absorbed by the Gramme machines. The driving engine from which power was taken made 60 revolutions per minute, and the Gramme armatures from 809 to 883 revolutions per minute. In the first place, a constant was sought for the motive power expended by the engine, the value of which was determined by diagrams; and from this constant the experiments were extended to trials with one or more Gramme machines, and by the difference the motive power absorbed was estimated. In the two tables appended the results are given of experiments during two hours and forty-eight minutes, ninety-four diagrams being taken from the cylinder of the steam engine while the experiments were in progress. The lamps employed were Serrin regulators. The four machines emitted a light of about 400 Carcel burners, with a mean of 1·903 HP. (French) as a mean for each machine, or 7·612 HP. for the four machines. At 800 revolutions per minute they gave a light very nearly equal to that from machines employed in the same workshop during the years 1874–75, which required a velocity of 1,800 turns to give their maximum light power. In Table 2, machine D with the highest number of revolutions (850) expended only 1·360 HP., giving on a Foucault photometer 81 Carcel burners, the light being surrounded by a ground glass globe; machine D therefore was, with regard to the others, in the worst conditions for light power. This is explained by the following law which governs the expenditure of motive power by dynamo-electric machines. The motive power absorbed by a Gramme dynamo-electric machine depends not only upon the intensity of the light required from the current, but upon the resistance in the circuit, which varies with the conductivity of the wires, the nature and quality of the carbons, the facility with which these produce the voltaic arc, and the greater or less resistance that the Gramme armature presents in its movement of rotation. It is therefore necessary to distinguish the motive power absorbed in producing the current.

During the twenty-five or thirty seconds which follow the commencement of movement, the Gramme machine absorbs about 67 per cent. in excess of its normal expenditure. This fact, previously observed by M. Tresca, proves not only a resistance due to inertia, but also that a force is necessary to establish the flow of the electric current. If the carbons have not been previously cut to a point, this time of increased expenditure of motive power will be longer. From this it results that in the setting up of a Gramme machine, in calculating the motive power required, it is necessary to allow that the engine should furnish for some periods 75 per cent. more than the motive power absorbed in normal working.

The results described were obtained with hard carbons 0·276 inch square in section. They burnt at the rate of 4·724 inches to 4·921 inches per lamp per hour, at a cost of about 5·1*d.* per foot, or say 2*d.* per regulator per hour. Allowing 8·023 HP. as the expenditure of motive power for four machines from a steam engine consuming 3·3 lbs. of coal per HP. per hour (at 14·5*d.* per cwt.), there is a cost per hour of 0·85*d.* in producing motive power for a dynamo-electric machine. This calculation neglects the increased motive power absorbed during some short periods when the machine is started. The superintendence of the Gramme machine and of the lamp necessitates an expenditure during the time of lighting of 2*s.* 4½*d.* per day, or 7*d.* cost of superintendence per hour, per machine, and per lamp. The same superintendence would be sufficient for a greater number of instruments. The charge of 2*s.* 4½*d.* per day supposes the man to have other employment when not engaged upon the machines. The total expenditure per hour for one Gramme machine with its lamp is 3·68*d.*

The following table gives a comparative result as to economy of the lighting of the Ducommun works by the electric light as compared with gas (the gas derived from oil):—

Lighting with Gas.			Lighting with Electric Light.		
Power of the Electric Light expressed in Gas Burners.	Cost per Hour.		Equivalent Power to the Electric Light of Four Lamps expressed in Number of Gas Burners.	Cost per Hour.	
	Without Interest and Wear and Tear.	With Interest and Wear and Tear.		Without Interest and Wear and Tear.	With Interest and Wear and Tear.
No. of Burners.	*d.*	*d.*		*d.*	*d.*
62	14·76	20·08	..	..	..
195	46·63	63·47	..	..	..
442	105·15	143·03	442	14·70	63·40

It is necessary to understand, in the estimation of the cost of the electric light, that a machine of

1,850 Carcel burners consumes for each 100 burners 0·415 HP.
300 " " " " 100 " 0·920 "
150 " " " " 100 " 1·700 "
100 " " " " 100 " 2·400 "
50 " " " " 100 " 4·400 "

For the preceding calculations there have been taken as data the number of hours of lighting per year, 500; power of light of four electric lamps (régulateurs), 320 Carcel burners, each burner of 0·925 inch exterior diameter, consuming 1·411 oz. (40 grammes) of oil[1] per hour; illuminating power of a Carcel burner, 8·69 stearine candles of ten to the kilogramme; illuminating power of a gas burner, consuming per hour 3½ cubic feet of gas, 6·280 candles; cost of 35 cubic feet of gas, 2½*d.*; initial cost of establishing gas lighting, per burner, 24*s.*

The following tables afford the data necessary for the determination of the cost of establishing lighting by means of a dynamo-electric machine:—

TABLE 1.—MOTIVE POWER ABSORBED by FOUR GRAMME MACHINES.

Number of Curves taken before and behind the Cylinder.	Pressure in Atmospheres.	Number of Revolutions of Motor.	Machines working.	Mean from Curves expressed in HP.	Observations.
1 to 4	3	..	Steam shafting, Root's blower No. 4, all tubes open.	7·373	..
5 to 15	3	60	Same as above, but with addition of four Gramme machines with lamps in normal position.	20·138 15·396	During 25 to 30 seconds at starting.

TABLE 2.—PHOTOMETRIC EXPERIMENTS.

Consump- of Oil in a Carcel Lamp during Experiments.	Number of Carcel Burners as measured by a		Apparatus and Observations.
	Foucault Photometer.	Bunsen Photometer.	
Grammes.			
39·30	79·6	80·7	Machine B, lamp No. 2 in a globe of ground glass, the three other lamps burning, but inclosed.
	88·7	95·6	Machine B, lamp No. 2 as before, three other lamps extinguished.
	106·3	122·2	Same, but without ground glass globe on lamp.
	85·0	85·3	Machine A, lamp No. 2 with ground glass globe.
40·00	103·0	103·2	Machine C, lamp No. 2 „ „ „
	81·0	68·7	Machine D, lamp No. 2 „ „ „
	86·5	86·8	Machine B, lamp No. 1 „ „ „
	51·8	77·6	Machine B, lamp No. 3 with globe cut out at base.
40·56	78·5	68·1	Machine B, lamp No. 4 with ground glass globe.

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[1] Colza.—P. H.

TABLE 2 (*continued*).—DYNAMOMETRIC EXPERIMENTS.

Number of Curves taken before and behind the Cylinder.	Number of Revolutions of Coil of Gramme Machine.								Mean HP. absorbed.
	Theoretical.				Actual.				
	A.	B.	C.	D.	A.	B.	C.	D.	
16—19	822	822	809	883	810	802 816	763	836 856	8·037
20—21	..	822	..	..	..	802 816	..	..	1·921
22—23	..	822	..	..	..	816	..	..	1·921
24—27	822	..	..	..	810	..	..	..	1·849
28—31	..	..	809	..	..	..	763	..	1·833
32—35	..	..	..	883	..	..	..	836 56	1·360
36—39	..	822	..	..	..	804	..	..	1·980
40—43	..	822	..	..	..	804	..	..	1·710
44—47	..	822	..	..	..	804	..	..	2·001

Pressure 3 atmospheres
Number of revolutions of motor 60 } throughout.

P. H.

Electric Counter for Machinery.

By S. BOZZONE, Director of Naval Construction in Italy.

(Rivista marittima, vol. ix., p. 105.)

This apparatus, of which a description and drawings are given, was invented by the Author for the purpose of better indicating the number of revolutions made by the main axle of a machine per minute, and to record the total number of revolutions during any required period of time. He considers that, of all the motive powers at the disposition of an engineer, that which is distinguished by the greatest simplicity in the mode of transmission is electricity. Independent of that complication of mechanism which is required in order to transmit the force of water, air, and steam to the points where resistance is to be overcome, and of the limit of the comparatively small distance for which such force can be transmitted, the electric fluid, passing through a wire, can almost instantaneously communicate motion to an apparatus at distances that may be called practically unlimited. Among the new applications of this agency for which the field is daily becoming more extensive, Signor Bozzone has considered that its adaptability to machinery for measuring and recording motion is remarkable.

The apparatus described (which has been patented in Italy) is contained in a box resembling that of a gas-meter, exhibiting three dials, one of which is that of an ordinary clock, with hour, minute, and second hands, and which is connected with the motive power and apparatus by isolated wires. On the axle, the revolutions of which are to be counted, a cam is fixed, which moves the end of a lever in each revolution; the lever being thrown either to left or to right, according to the direction of the revolution. At the moment of its displacement, the distant end of the lever makes electric contact with one or the other of two electro-magnets, which attracts a metal armature, giving motion to a lever provided with a hook, that pulls a ratchet wheel forward one tooth. The axle of this ratchet wheel is concentric with a dial bearing a graduated circle, which is numbered from right to left without, and from left to right within. Two hands are borne on the axle, one indicating the direct, the other the retrograde motion. In the centre of the visible part of the apparatus, between the clock and the first dial, is a larger dial having a single hand, and graduated, like the first dial, into eighty divisions.

The hand of the second dial advances, a degree at a time, with each revolution of the first wheel. At the end of every minute a bell is struck by means of a detent set in motion by the clock, and the arrow on the central dial is released and flies back to zero. This portion of the apparatus counts the revolutions minute by minute, but makes no record of the number. The hands of the first dial continue their motion, and thus indicate the total number of revolutions in each direction at any given period of time. The apparatus is fitted with an "interrupter," to throw it out of gear when not required. It has been fixed on board the ironclad "Prince Amadeus," and is said to have acted with perfect precision.

F. R. C.

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